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INTEGRATED MAINTENANCE INFORMATION SYSTEM
DIAGNOSTIC DEMONSTRATION

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This report has been reviewed and is approved for publication.

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13. ABSTRACT (Maximum 200 words) <p>This report describes a proof-of-concept effort to demonstrate the Integrated Maintenance Information System Diagnostic Module (IMIS-DM). The IMIS-DM uses a small portable computer and special purpose software to generate and provide diagnostic advice to the technician for use in troubleshooting Air Force weapon systems. The demonstration was conducted at Homestead AFB, Florida, in May 1989. The F-16 Fire Control Radar was used as the testbed for the demonstration. The project demonstrated that a small, portable computer can interface directly with the MIL-STD-1553 multiplex control bus of the F-16, act as bus controller, initiate built-in tests, read and analyze the resulting fault data, provide diagnostic advice to maintenance technicians, and present automated technical procedures to guide the technician in performing tests and corrective maintenance. The IMIS-DM was tested by having technician use the system to perform troubleshooting tasks on the radar system. The technicians were able to successfully solve all troubleshooting problems used in the demonstration. The demonstration results indicate that the IMIS-DM will provide an effective diagnostic capability for the IMIS and will provide the basis for significant improvements in the ability of Air Force maintenance personnel to perform diagnostic tasks.</p> <p><i>Review and Test - 7/4/90 Satisfied requirements FMS</i></p>			
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SUMMARY

The Air Force Human Resources Laboratory is developing a demonstration prototype Integrated Maintenance Information System (IMIS). The IMIS will be an automated system designed to provide the maintenance technician with a single source for all information necessary to do his or her job. It will include technical order information, diagnostics information, maintenance records, supply information, management information, and training materials. The Laboratory is conducting a systematic program to develop the technologies required for the IMIS. Diagnostics aiding techniques have been developed as part of this program. These techniques are incorporated in the IMIS Diagnostic Module (IMIS-DM). The IMIS-DM is now ready for testing. This report describes the first of two efforts designed to demonstrate and test the IMIS-DM.

The IMIS Diagnostics Demonstration was conducted at Homestead AFB, Florida, in May 1989. The F-16 Fire Control Radar was used as the testbed for the demonstration. The project demonstrated that a small, portable computer can interface directly with the MIL-STD-1553 multiplex control bus of the F-16, act as bus controller, initiate built-in tests, read and analyze the resulting fault data, provide diagnostic advice to maintenance technicians, and present automated technical procedures to guide the technician in performing tests and corrective maintenance. The IMIS-DM was tested by having technicians use the system to perform troubleshooting tasks on the radar system. The technicians were able to successfully solve all troubleshooting problems used in the demonstration. The demonstration results indicate that the IMIS-DM will provide an effective diagnostic capability for the IMIS and will provide the basis for significant improvements in the ability of Air Force maintenance personnel to perform diagnostic tasks.

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PREFACE

This report summarizes research and development (R&D) accomplished under Project 2950, Integrated Maintenance Information System (IMIS), Work Unit 2950-00-06, F-16 Diagnostics Demonstration. The purpose of the study was to demonstrate the diagnostic technology developed for the Integrated Maintenance Information System (IMIS).

The IMIS Diagnostic Demonstration (IMIS-DD) provided the first test of the IMIS diagnostic capability in an operational environment. General Dynamics Electronics (GDE) Division was the prime contractor for the effort. However, accomplishment of the effort required the coordinated support of several other organizations. The major portion of the technical data development was accomplished in-house by AFHRL staff scientists. The software for the diagnostics module was developed by Systems Exploration, Inc. (SEI). The portable maintenance aid (PMA) and Authoring and Presentation System software used for the study were developed by AFHRL in-house, with extensive support from Systems Research Laboratories (SRL). Support for the field test portion of the study was provided by SEI and Applied Science Associates (under contract with GDE).

Many Government and contractor personnel played significant roles in the effort. Key personnel are identified below.

Air Force Human Resources Laboratory

Terry Miller. Originated the diagnostic techniques which provide the basis for the IMIS diagnostic module.

Captain Randy Link. Served as Program Manager for most of the effort, and director of many of the modifications to the data base authoring system.

Lieutenant Janet Murphy. Served as Program Manager for the last part of the project and responsible for data development, validation, and evaluation of the final product.

Captain Dwayne Mason. Developed and improved the diagnostic module and provided general support throughout the effort.

Captain Mark Earl. Designed and developed the authoring software.

Gail Hudson. Directed the development of the portable maintenance aid used in the study.

Captain Gail McCarty. Developed the maintenance data base.

Dr. Donald Thomas. Provided technical support throughout the project.

31 Tactical Fighter Wing, Homestead AFB, FL

Colonel James Cushman, Deputy Commander for Maintenance. Provided the facilities and personnel required for the field demonstration.

SMSgt Prince, SMSgt Bolton, and TSgt Manka. Coordinated Wing support for the demonstration and provided technical guidance.

General Dynamics Electronics

James Brown. Served as Project Manager for development of the aircraft interface software, portions of the data base, and testing of the final product.

Neal Ostrem. Developed the 1553 bus software that interfaces with the F-16 aircraft.

Mike McKnerney. Developed modifications to the presentation software to accommodate access to the aircraft.

General Dynamics Ft. Worth (Hill AFB office)

Lloyd Huff, Phil Ralphs, and Curtis Ockerman. Assisted with development of the diagnostics data base and testing of PMA/F-16 data bus interface.

Applied Science Associates, Inc.

Reid Joyce. Provided guidance to GDE in the area of Human Factors and served as data collector for the field demonstration.

Systems Exploration, Inc.

Garth Cooke. Managed the effort to develop the IMIS Diagnostic Module algorithms and software.

Johnnie Jernigan. Assisted in the development of the diagnostic module algorithms, selected the problem set used in the demonstration, and provided technical assistance for the field demonstration.

Systems Research Laboratories (SRL)

Jerry Brainard. Managed SRL activities in support of the development of the PMA and APS software, and provided technical assistance during the field demonstration.

Jane Slayback. Led the team of programmers that developed the APS and PMA software.

Rick Chaney, John Miles, and Chris Broadbent. Provided technical assistance for the demonstration.

Dave Groomes. Developed the graphics for the data base used for the demonstration.

TABLE OF CONTENTS

I. INTRODUCTION	1
Definition of the IMIS Program	1
IMIS Diagnostics Demonstration	2
Background	3
Computer-Based Maintenance Aids (CMAS).....	3
APS Project	4
Maintenance Diagnostic Aiding System.....	5
IMIS-DD Demonstration Approach	6
II. IMIS-DD TECHNOLOGIES	7
IMIS Diagnostic Module	7
Authoring and Presentation System.....	11
APS Data Base.....	12
Authoring Subsystem.....	12
Presentation Subsystem APSPresent.....	13
Portable Maintenance Aid (PMA)	14
PCMAS I	14
PCMAS II	14
III. METHOD	15
Testbed Selection.....	15
Development of Diagnostic and Maintenance Data	16
Test Problem Selection	19
Evaluation Approach.....	20
Subjects.....	20
Questionnaires	22
Procedures.....	22
Final Debriefing	24
IV. RESULTS.....	24
Performance Data.....	24
Performance Observations.....	24
Task Debriefing.....	30
Questionnaire Results.....	30
Final Debriefing	31

V. DISCUSSION.....	33
Conclusions.....	35
Follow-On Efforts.....	35
IMIS-DM Redesign/Enhancement.....	35
Small PMA	35
Content Data Model	36
Authoring and Presentation System Revision.....	36
Improved User Interface.....	36
F/A-18 Diagnostic Demonstration	36
REFERENCES	37
BIBLIOGRAPHY	38
ACRONYMS.....	39
APPENDIX A: IMIS-DD FAULT INSERTION LIST	41
APPENDIX B: USER EVALUATION QUESTIONNAIRE	48
APPENDIX C: SAMPLE DIAGNOSTIC RUN.....	58

LIST OF FIGURES

Figure

1 Computer-Centered Integration Versus Technician Centered Integration.....	9
2 IMIS-DM Logic Flow	10
3 Fault Representation Movement.....	11
4 PMA used for IMIS Diagnostics Demonstration	15
5 Technician using PMA during demonstration	23

LIST OF TABLES

Table

1 Reachability Matrix	8
2 Simulation of Faults	20
3 Specialties and Skill Levels of Demonstration Subjects	21
4 Biographical Data for Demonstration Subjects	21
5 Order of Problem Performance	25
6 Performance Time in Minutes	25
7 Questionnaire Responses.....	31

I. INTRODUCTION

Recent developments in information processing technology and computer design have made possible the automation of many maintenance information processes that were traditionally manual operations. These processes include interacting with maintenance data bases, obtaining and using technical orders and instructions, downloading and evaluating aircraft built-in-test (BIT) results, and using historical data to diagnose aircraft malfunctions.

A number of automated information systems have been developed, or are under development, to automate these processes for use by Air Force maintenance technicians. However, these systems are being developed independently, and as a result, use different computer hardware and human/computer interaction techniques. This requires the technician to learn to use several complex systems, making his/her already difficult job more difficult. A single system is needed which integrates all of the information systems so that they may be accessed using common hardware and human/computer interaction protocols. With such a system, the technician would be required to learn only one set of protocols to use the system to obtain the information necessary to do the job.

The Air Force Human Resources Laboratory (AFHRL) has established the Integrated Maintenance Information System (IMIS) program to meet this need. The Laboratory is systematically developing and evaluating the capabilities required for the IMIS. The present report describes the work performed in a recently completed effort to develop and evaluate key capabilities, the IMIS Diagnostics Demonstration (IMIS-DD).

Definition of the IMIS Program

IMIS is a demonstration prototype maintenance-aiding system that will communicate with other maintenance computer systems, both on-aircraft and ground-based, to provide a single source of information to meet the information requirements of maintenance personnel. IMIS will access, integrate, and display maintenance information for base-level aircraft maintenance technicians. The IMIS will include interactive interfaces with the computer systems on the aircraft and with maintenance and management ground-based computer systems. In addition, it will operate independently for stand-alone troubleshooting and corrective maintenance tasks.

Technicians will use a portable, ruggedized computer as the single information access unit for all the data needed to accomplish maintenance tasks. The system will display graphic and procedural technical instructions, provide intelligent diagnostic advice, provide aircraft battle damage assessment and repair aids, interrogate aircraft BIT systems, and analyze in-flight parameter data and aircraft historical data. It will also provide easy, efficient methods for the technician to receive work orders, report maintenance actions, order parts, complete computer-aided training lessons, and transmit messages throughout the maintenance complex. As originally envisioned by AFHRL scientists, the IMIS system will consist of five major elements:

1. The technician's portable maintenance aid (PMA).
2. Maintenance information workstation (MIW) in the maintenance complex connected to the ground-based computer systems and networks.
3. Aircraft interface panel (AIP) for interfacing with aircraft computers and sensors.

4. Integration software that combines the information from multiple sources and presents the data in a consistent way to the technician.

5. Applications software that uses information from various sources to assist in troubleshooting and identifying the causes of malfunctions and performing maintenance.

IMIS Diagnostics Demonstration

The IMIS-DD project was a proof-of-concept demonstration of several key aspects of the IMIS program. These concepts included the use of a computer-based PMA to provide intelligent diagnostic advice for the technician, interfacing the PMA with the aircraft data bus, and integrating maintenance technical data with the diagnostic advice. The primary objective of the effort was to test and demonstrate the diagnostic capability provided by the IMIS Diagnostic Module (IMIS-DM) and not to test a fully capable IMIS system. All areas of the IMIS, including those tested in the IMIS-DD, continue to be researched, evaluated, and enhanced. The diagnostic capabilities demonstrated for the IMIS-DD include:

1. automated generation of diagnostic advice.
2. concepts for presenting diagnostic guidance such as giving the technician the choice of whether or not to follow recommendations, and providing decision support information (e.g., component probability of failure data).
3. integrating diagnostic instructions with maintenance instructions.
4. interfacing the PMA with the aircraft MIL-STD-1553 (1978) data bus to initiate the BIT and obtain aircraft systems status information.

In addition, the effort addressed several secondary objectives, including:

1. testing techniques for presenting technical data on a PMA.
2. testing human computer interface techniques for presenting diagnostic and technical data.
3. demonstrating the use of a "neutral," format-free data base for maintaining maintenance technical data.¹
4. testing the capability of the AFHRL Authoring and Presentation System (APS) to create data in a neutral format, and presenting the data on a PMA.
5. testing the capability of the APS to handle technical data for several aircraft configurations, and automatically presenting the proper data for a specific aircraft.

¹A neutral data base contains no format information to control the presentation of the data. The data include the data elements (information to be presented) plus codes which identify the type of information (e.g., header, graphic or procedural step). Rules for formatting the data are incorporated in the software used to present or print the data.

Background

For several years AFHRL has conducted a systematic research and development (R&D) program to develop the technologies required for the IMIS. To date, these efforts have concentrated on the development of techniques to (a) use computers to present maintenance technical data, (b) provide economical techniques for creating and storing technical data on computer systems, (c) use computers to create and present automated diagnostic advice for technicians, and (d) provide effective techniques for humans to interact with the computer to obtain the information that they need. This research has resulted in the development of prototype computer-based technical data systems for intermediate-level and on-equipment maintenance; the IMIS-DM; an authoring system for creating technical data in a neutral format; a presentation system for displaying the data on a variety of computers; and specifications for use in procuring technical data in a neutral format. In addition, work is presently in progress to conduct a more comprehensive test of the IMIS-DM and to develop a full-scale prototype IMIS to fully test the IMIS concept. Earlier efforts which have had a major influence on the IMIS-DD effort are briefly described below. Efforts which played a major role in the IMIS-DD are described in detail in Section II.

Computer-Based Maintenance Aids (CMAS)

Since 1976, AFHRL has conducted R&D to develop the technology for the presentation of technical data on an automated system (Thomas and Clay, 1988). This research recognized the potential of an automated technical data system to improve performance of maintenance personnel and reduce the cost of maintaining the Air Force technical data system. Emphasis was placed upon the design of technical data presentation techniques and procedures tailored to meet technicians' needs. Emphasis was also placed upon developing data access techniques to make it easy for technicians to locate needed information and developing effective formats for presenting that information. Experienced maintenance personnel from operational units were involved in all phases of the program (as consultants and test subjects) to ensure that the needs of the maintenance technician were met and the techniques developed were suitable for use in actual maintenance operations.

A laboratory demonstration, two prototype systems for off-equipment maintenance, and two prototype systems for on-equipment maintenance were developed in the CMAS project. Although the prototype systems were not intended for actual operational implementation, they were designed to fully test all required functions and to accurately simulate an operational system. The prototypes were tested in maintenance shops of operational units to provide realistic evaluations of the systems under operational conditions. Specifications for both (a) technical data content and (b) system hardware and software were developed based upon the knowledge gained from development of the prototypes and from experience gained in the field tests.

The basic approach taken to achieve the project objective was to first conduct feasibility studies of a CMAS, identify the basic features that should be provided by such a system, develop and evaluate prototype systems, and develop draft specifications for use in developing and procuring systems for operational use. The feasibility studies were accomplished and four prototype systems were developed. Evaluations of three prototypes were performed; the fourth prototype was evaluated in the IMIS-DD project.

The feasibility studies and prototype evaluations achieved the following results:

1. established the feasibility of automated technical data presentation systems,
2. demonstrated they can effectively present technical data for use by technicians,

3. demonstrated technicians will readily accept and use automated technical data presentation systems,
4. demonstrated that diagnostic procedures can be effectively presented on a CMAS, and
5. provided the basic human factors requirements for a CMAS.

The information gained from the feasibility studies and evaluations of the first three prototypes provided the basis for the development of the fourth prototype, the Portable Computer-Based Maintenance Aids System II (PCM AS II). The PCM AS II computer was used as the PMA for the IMIS-DD effort.

The PCM AS II computer was developed to provide a small, rugged, lightweight computer system for use in evaluating techniques for presenting technical data and diagnostic advice for on-equipment maintenance. It was based upon an earlier prototype (PCM AS I) which was found to be too slow to generate the graphics required for presentation of technical data. The PCM AS II computer weighs 15 pounds and its dimensions are 15 x 12 x 3 inches. Technical data for presentation on the system are maintained in removable, 3-megabyte memory cartridges. The PCM AS II is operable from a battery pack (6- to 8-hour capacity), aircraft system power, an auxiliary power unit, or standard commercial power (110V AC). The keypad consists of eight programmable function keys, a numeric keypad, and cursor control keys. A built-in 1553 data bus board provides the capability to communicate directly with aircraft systems served by the aircraft's MIL-STD-1553 data bus. The PCM AS II may be operated in a stand-alone mode or in conjunction with a workstation that provides a full keyboard, hard disk drive, printer, and additional communication capabilities. Software developed for the system includes a UNIX-based operating system and applications software for diagnostic aiding and presentation of technical data.

The PCM AS project is described further in Section II.

APS Project

In conducting the CMAS program, it was recognized that the manner in which the data base is created and maintained will have a significant influence on the success of an automated technical data system. Efficient techniques must be available to create the data and incorporate the complex coding required for the display of technical data on a screen. Further, these data must be stored such that they can be displayed on a variety of computer systems without change. In addition, it would be desirable to be able to produce printed copies of the data from the same data base. With these requirements in mind, an analysis was made of technical data requirements, data base management techniques, and data coding techniques. A data coding scheme and data base management approach were then developed to meet these requirements. The APS was then developed to provide a means of efficiently creating the data, presenting the data on a variety of computer systems, and printing these data according to specified formats without changing the data base. The data base developed using the APS is known as a neutral data base, inasmuch as it does not contain format information and is independent of the computer system that will be used to display the data.

The resulting data base contains the technical data to be displayed to the user. The control codes used to display the data are inserted by a software package called DataLoad, which is specific to the output device to be used. DataLoad puts small amounts of formatting information into the data and checks the data for internal consistency. The data are then ready for display on the designated output device using a version of the APS presentation software that has been adapted for that device (only relatively minor modifications to the presentation software, for the screen and keyboard functions, are required to adapt it to a particular output device).

The APS project addresses three areas important to the success of the full IMIS:

1. A data base structure capable of representing the complex data relationships found in digital maintenance information created for interactive use.
2. Authoring system software to reduce the time and effort required to design and produce the data.
3. Presentation system software to provide access to, and interact with, the information contained in the data base.

The data base used by the authoring system of APS provides the flexibility required to represent any type of document, including the complex interrelated data found in technical orders (TOs). The data base may contain TOs written for many types of weapon systems and many configurations of a weapon system. The basic structure of the data in the APS data base is a hierarchical tree. At each node of the tree is a paragraph of technical information. Supporting information such as tables, graphics, or cautions are attached to the paragraph by the author through simple commands. APS maintains the relationship of each paragraph with its neighboring paragraphs, and each paragraph knows where it fits into the hierarchy. This relational tree structure allows the presentation of information to be tailored to the needs of the user. The authoring and presentation system is described in detail in Section II.

Maintenance Diagnostic Aiding System

A critical function of the IMIS will be to provide the maintenance technician with intelligent diagnostic advice to aid the technician in the troubleshooting of sophisticated weapon systems. In 1983, AFHRL began an effort to develop and advance technology to generate diagnostics advice using a small, portable computer. This research led to the development of the Maintenance Diagnostic Aiding System (MDAS). The MDAS provided the basis for the diagnostic module used in the IMIS-DM.

The MDAS provides a wide range of recommended actions and information to assist the technician in selecting an efficient sequence of tests and maintenance actions to rapidly repair the system. The MDAS was designed to work efficiently in an on-equipment maintenance environment where the technician's job is to isolate problems to a replaceable component level rather than to the lowest level at which a failure might occur. However, MDAS will work equally well at the intermediate and depot levels of maintenance with appropriate adjustments to the data base.

MDAS uses algorithms to identify the test and repair activity sequence most likely to result in a repaired system in the minimum amount of time. The algorithms recommend the best next action based upon several parameters including the likelihood of component failures, and task or test accomplishment times. The diagnostic module determines the next recommended action dynamically at each stage of the diagnostic session, rather than exhaustively precalculating these actions to establish a fixed-sequence decision tree. In addition, the algorithms provide the technicians with lists of available actions which might prove effective in repairing the system. The lists are rank-ordered by calculated probability of success. The highest probability action is recommended; however, the technician is free to choose among the available alternatives. Once an action is completed, the next recommended action is calculated based upon the results of the previous action.

The algorithms and the data requirements developed for the MDAS were refined and used to develop the IMIS-DM used in the IMIS-DD project. The refinements included the incorporation of the following capabilities:

1. multiple-outcome (nonbinary) tests,
2. availability of resources on base,
3. ability to focus troubleshooting on mission-critical components,
4. calculation of estimated maintenance time, and
5. training/simulation.

The IMIS-DM is described in detail in Section II.

IMIS-DD Demonstration Approach

The IMIS diagnostic technology was demonstrated by having Air Force maintenance technicians use the PMA and the IMIS-DM software to troubleshoot faults in an Air Force weapon system. To accomplish the demonstration, the following tasks were performed:

1. The Fire Control Radar (FCR) system on the F-16 aircraft was selected as the testbed.
2. Technical data were developed for the FCR system using the APS. The technical data included diagnostics data and the maintenance instructions needed to support the diagnostic tasks.
3. Software was developed to interface the PMA and the aircraft's MIL-STD-1553 database. The software provided the capability to initiate the FCR BIT and feed the results to the IMIS-DM for use in determining the recommended diagnostic strategy.
4. The APS presentation software was modified to incorporate the requirements of the diagnostic module and to incorporate improved human computer interface techniques.
5. Representative malfunctions in the Fire Control Radar were identified, and means of simulating these malfunctions were identified for use in the demonstration.
6. Air Force technicians at Homestead AFB, Florida, used the PMA and diagnostic module to diagnose the simulated faults. Their performance was closely monitored by a trained observer to identify problem areas and to assess user reactions to the system. In addition, the technicians were asked to complete a questionnaire to give their reactions to the system and recommendations for making it more effective.

The methodology for the demonstration is described in detail in Section III. The findings are provided in Section IV.

II. IMIS-DD TECHNOLOGIES

The IMIS-DD project tested and applied several AFHRL technological developments. Modifications were made as necessary for extending these developments to meet program needs. The major developments used in the project are described in this section.

IMIS Diagnostic Module

Embedded diagnostics on today's aircraft, sophisticated as these on-board diagnostics are, still suffer from high false alarm rates and ambiguous fault indications. As weapon systems of the future become more complex, the need for accurate diagnostic data becomes more critical. Failure of on-board diagnostics to detect and isolate faults requires the technician to use troubleshooting tools external to the aircraft. The IMIS-DM is one such tool (Cooke, Jernigan, Huntington, Myers, Gumienny, & Maiorana, 1990; Cooke, Jernigan, Myers, Maiorana, Link, & Mason, 1990). The IMIS-DM advises the maintenance technician as to the best troubleshooting strategy to isolate a fault and repair a disabled aircraft.

The IMIS-DM is a computer-based system for providing intelligent diagnostic advice for use by maintenance technicians to troubleshoot problems in aircraft systems. It integrates a variety of data (including design data, historical data, repair times, test times, mean time between failure data, and parts information) to guide the technician in the fault isolation process. The system includes a sophisticated algorithm to calculate the most efficient diagnostic strategy, which is then recommended to the technician. The technician has the option of following the recommended action or selecting another action from a list of options provided by the IMIS-DM. In addition, the system provides the capability for the technician to call up a variety of information, such as historical data, to assist in his/her decision process.

A key design feature of the IMIS-DM algorithms is optimization of the repair and recovery time of a weapon system rather than time to fault isolation. This philosophy takes advantage of scenarios in which a rectification action has a high probability of repairing a fault faster than does isolating a fault through tests and then repairing. For example, if there is a 95% probability that a line replaceable unit (LRU) is faulty and the time to repair is short, then the IMIS-DM would recommend replacing the LRU. On the other hand, if an LRU has a 50% failure probability and will take an hour to replace, then the IMIS-DM would recommend testing first to verify that the LRU is faulty. The IMIS-DM uses a split-half diagnostic strategy to determine the best test to perform. The split-half algorithm uses test result information and testing times to maximize information gained per unit cost. A comparison is made between the best test and a dominant action (an action with a very high probability of success) that would repair the suspected component. This comparison is based on the failure probability of the suspected component and the time required to perform the repair action.

The IMIS-DM diagnostic decision logic is kept separate from the weapon-system-specific data to ensure applicability to any weapon system; this capability is implemented using generic mathematical algorithms. In order to carry out a troubleshooting strategy, the IMIS-DM requires lists of faults, symptoms, tests, and repair actions for a component under test at a specific level of maintenance (organizational, intermediate, or depot) and the interrelationships between these items. The level of maintenance is stressed as the possible number of faults, symptoms, tests, and repairs at the intermediate and depot levels are much greater than at the organizational level. The IMIS-DM creates a reachability matrix (see Table 1) formed by mapping these parameters of the system under investigation.

Table 1. Reachability Matrix

Faults	Symptoms				Tests		Rectification Action			
	Fault Codes (Machine)		Symptom Description (Human)				MA	S	MA	S
	FC1	FC2	SC1	SC2	T1	T2				
1A	1	1	0	1	1	0	1	0	0	0
1B	0	0	1	0	1	0	0	0	0	0
2A	1	1	0	1	0	0	0	0	0	1
2B	0	1	0	0	0	1	0	1	1	1
MA = Maintenance action (e.g., Align, Adjust). S = Swap for "new" item.										
							1	2	COMPONENTS	

The IMIS-DM recommends the best test or repair action based upon the most information gained for the cost.² However, the technician is not locked into this recommendation. The technician is able to control the diagnostics process by approving or disapproving the IMIS-DM recommendations. The technician can rely on his or her experience and knowledge to direct the diagnostics. The IMIS-DM provides three ranked lists for the technician: (a) ranked rectifications, (b) ranked tests, and (c) interleaved tests/rectifications. All the actions presented will result in some useful information for continuing diagnostics. The technician has the option to view the ranked tests and rectifications with their associated fault probabilities and performance times. The technician also has the ability to query supply data, historical information, BIT, and other available sources of diagnostic data to aid in troubleshooting. Once the technician has decided upon a course of action, the computer provides the necessary technical data to support the choice. This built-in flexibility allows maintenance technicians to call upon their own knowledge and experience to facilitate recovery of the weapon system. This technician-centered approach toward troubleshooting is highly preferable to the computer-centered approach (see Figure 1) for two reasons: (a) It takes advantage of any unique information that the technician may have about the existing situation, and (b) it serves as a motivator to the technician by allowing use of his/her own knowledge.

The heart of the IMIS-DD diagnostics is a fault-based modeling scheme which models components in a particular system as a collection of potential faults.³ This approach uses

²The cost factor used for the demonstration was "time to perform the action."

³For discussion purposes, "fault" is used to represent potential causes of a failure of components or something causing the need for a maintenance action. It is recognized that components are not necessarily faulty; but for simplicity, they are referred to as faults.

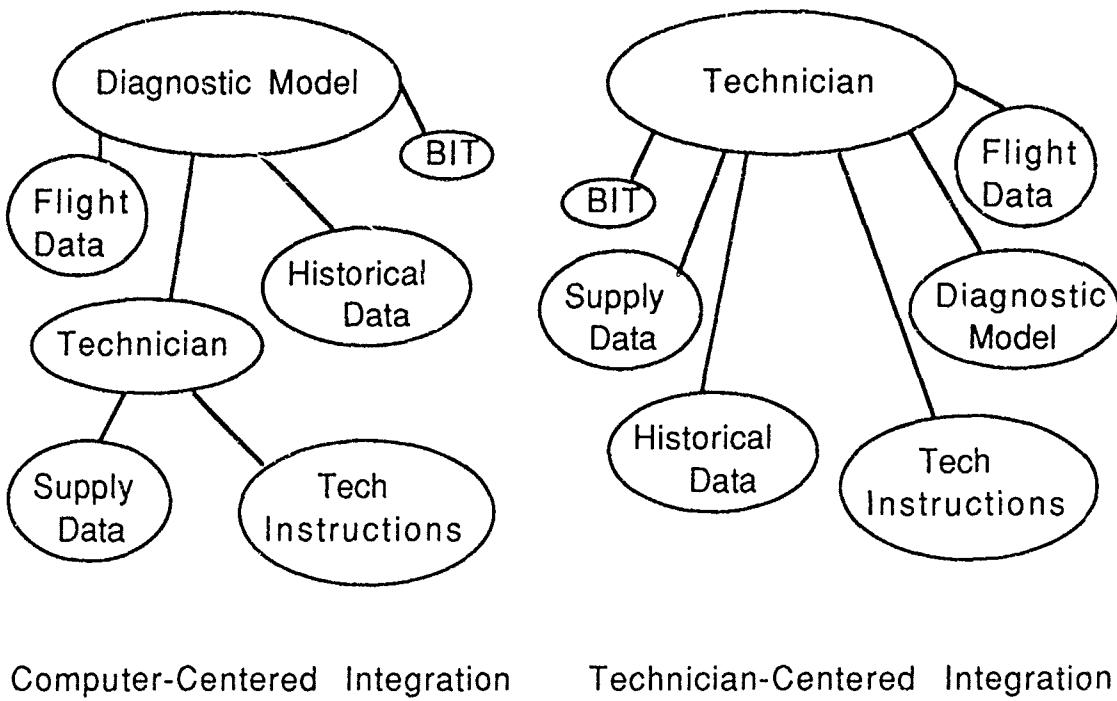


Figure 1. Computer-Centered Integration Versus Technician-Centered Integration.

symptoms to implicate a set of suspected faults, tests implicating or exonerating faults, and repair actions to rectify faults.

A multiple-fault scenario can be tackled by the IMIS-DM through fault manipulation. Fault manipulation is based on distribution of fault probabilities for the symptoms being considered, how the symptoms span the set of faults, the lower probability of independent events occurring simultaneously, and the influence of time required to complete each possible action. Basically, the system tracks multiple faults by identifying the potential faults and combinations of faults, spanning the most symptoms, then isolating and repairing the actual faults until the symptoms are no longer present and the system passes a functional check. The order in which the faults are isolated and repaired depends on the recommendations of the IMIS-DM. The diagnostic algorithms utilize all available information to make these recommendations.

A troubleshooting session begins by initializing the fault/symptom data through manual or automatic data entry of all available information such as BIT results, pilot-observed failures, and/or through system health information downloaded from the MIL-STD 1553 data bus (see Figure 2, Logic Flow). During this initialization process, equipment and parts availability (updated from a link to the supply computer) can be entered, as well as aircraft configuration (e.g., model type and set-up, such as nuclear or conventional) and critical fault information the IMIS-DM will use in troubleshooting. Knowing the availability of equipment and parts enables the IMIS-DM to mark each action requiring the unavailable items. These actions will not be recommended by the IMIS-DM. Criticality is a term used to designate some system functions essential for operational requirements. All potential faults contained in the critical components are identified as critical. The IMIS-DM searches for plausible faults (implicated by symptoms) identified as critical. This set is then given special consideration in developing recommended actions.

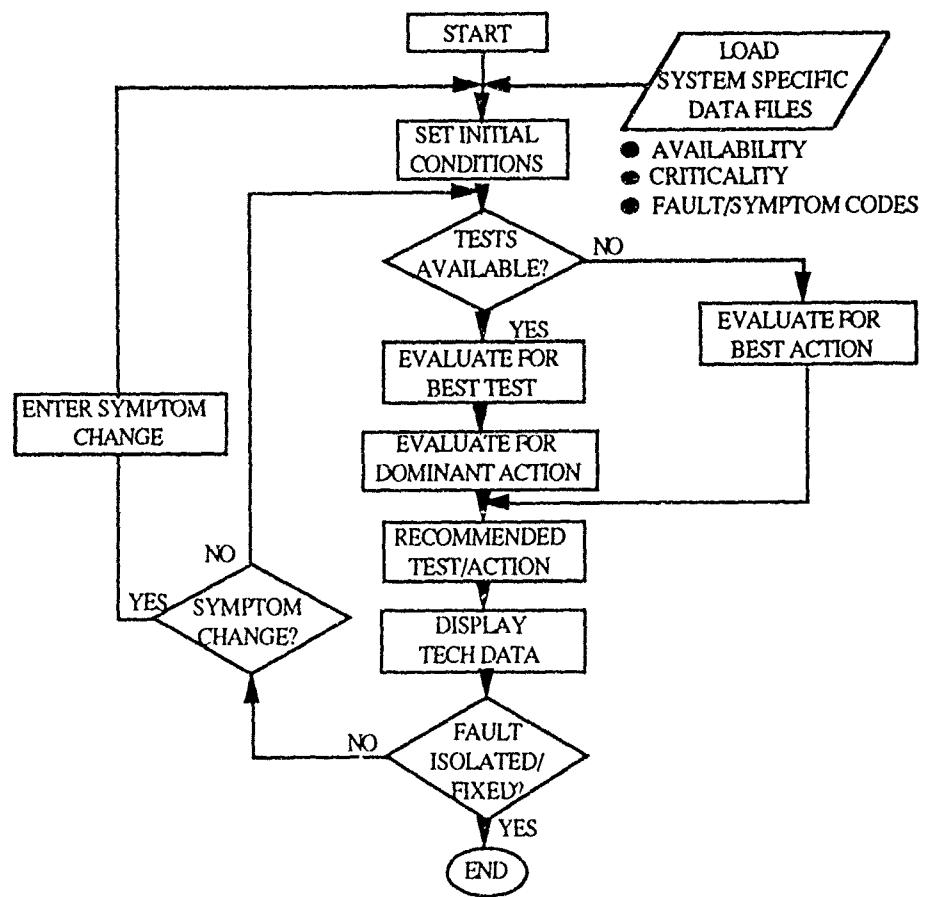


Figure 2. IMIS-DM Logic Flow

With this information, evaluations for best tests and rectifications can be determined. As the maintenance technician performs test and repair actions, faults will be placed into various categories. The category depends on the result of the test or a functional check conducted after the repair action. The fault categories consist of the following: (a) the Union set, containing all possible faults for all noted symptoms; (b) the Plausible set, containing faults currently under examination; (c) the Exculpated set, containing faults proven good by a passed test; (d) the Maybe set, containing faults in combination with exculpated faults provided they are not part of another fault combination still in the Plausible set; and (e) the Rectified set, containing faults associated with the repair action (all the faults that could possibly be fixed by performing that particular action).

A graphical representation of each possible fault changing during the diagnostic process is shown in Figure 3. The Plausible set is formed after initialization. The technician can proceed with the actions the IMIS-DM has recommended, or an action of his/her own choice. The objective of the diagnostic algorithm is to exculpate all the faults in the plausible set and return no symptoms. If a test is performed and the outcome of that test is a pass, the potential fault(s) will be placed in the Exculpated set. If the outcome is a fail, the potential fault(s) will remain in the Plausible set. Whether the test passes or fails, the IMIS-DM will use the outcome information to update the fault/symptom relationships. If a repair action is completed, a functional check will be performed to verify that the repair has removed the suspected fault(s). If the functional check

passes, the fault will be placed in the Rectified set. A failure of the functional check will update the fault/symptom relationships and keep the fault(s) in the Plausible set. A fault that is in combination with an exculpated fault is placed in the 'Maybe' set. When the Plausible set becomes empty and the failure has not been resolved, plausible faults from the Maybe and Rectified sets will be brought back into the Plausible set to continue diagnostics until the actual fault(s) is found.

For a detailed description of the IMIS-DM, see Cooke, Jernigan, Huntington, et al. (1990) and Cooke, Jernigan, Myers, et al. (1990).

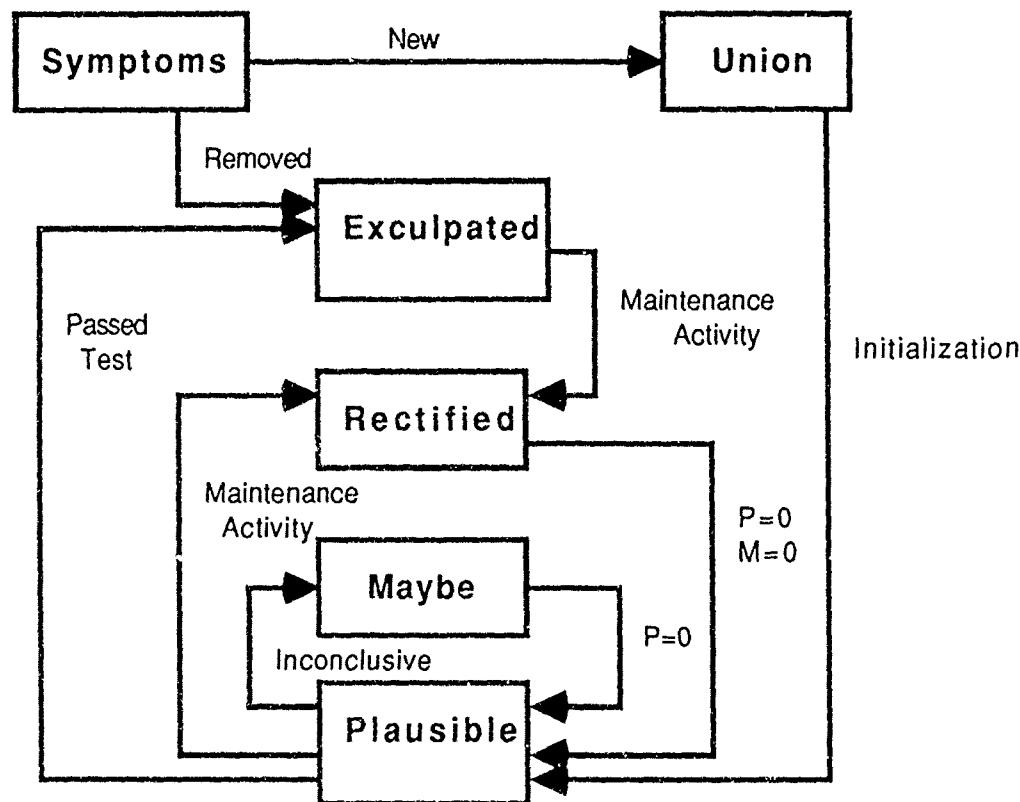


Figure 3. Fault Representation Movement.

Authoring and Presentation System

Technical data for the IMIS-DD project were prepared in a neutral data format using the Authoring and Presentation System developed by AFHRL. APS was developed as a part of ongoing AFHRL in-house research examining the technical issues of creating a maintenance data base flexible enough to create and present all types of data required for maintenance. Key requirements are to present the data on different computer systems and in different formats without having to modify or reauthor the data. These data could range from interactive training material to procedural, graphic-intensive job guides. The IMIS-DD project was the first test of the APS software on a large-scale basis, and was a major test of the software and authoring concepts upon which it was based. Numerous changes were made to the presentation portion of the software during the course of the project in order to accommodate the requirements of the IMIS-DM.

The APS is composed of three primary elements:

1. The data base, in which the maintenance technical data are maintained.
2. The authoring subsystem, which provides tools to help the author create the data in the form required for the data base.
3. The presentation subsystem, which extracts the data from the data base and presents the data on a specific computer system according to specified formats.

Each element of the APS is described briefly below.

APS Data Base

The APS data are maintained in a relational data base designed specifically for this application. The relational data base provides the flexibility required to represent the complex, interrelated data found in technical orders. The data are organized in a hierarchical representation defining the structure of the data base and the interrelationships between the data elements. The structure represents the data elements in a linear, or sequential, format before DataLoad is performed. DataLoad puts the data into a tree format for easy access; each node of the tree represents an element of the data. Each node may contain:

1. the data, or the location of the data if the data are already stored elsewhere in the data base.
2. codes indicating the relationships of the element to other elements in the data. In addition, they may identify related information (such as theory of operation or parts information) the user may wish to access.
3. various attributes of the data element including:
 - a. verification Status - the identification of whether or not the data element has been verified.
 - b. weapon Configuration - a code identifying the particular configuration or model of the aircraft system to which the data are applicable.
 - c. version - the version of the technical text.
 - d. track Level - the skill level of the intended user (novice, journeyman, expert, etc.).
 - e. security classification of the information.

The data base is designed to eliminate redundancies. This makes it possible to use the same text or graphic material multiple times, but store it only once in the data base. For example, an illustration which is used in many different procedures is stored only once.

Authoring Subsystem

The authoring subsystem is a tool to assist the author in creating data in the form required for the APS data base. The APS Authoring software (APSAuthor) provides the technical writer with a word processor interface and authoring tools required to create the data. APSCreator

provides word processor functions to assist the author in linking the data elements created to other related data elements. Word processor functions include (a) automatic indentation and paragraph numbering, (b) word wrap, (c) insert and overwrite text, and (d) block manipulations to copy and cut-and-paste information.

APSAuthor provides tools to assist the author in linking data elements and graphics together. Data elements are linked automatically when specifically created to go together. For example, when a warning is created to support a specific step in a procedure, the warning is automatically linked to that step. If a step is to be linked to a previously created data element or graphic, the system provides a menu of data elements from which the author may select. When the author makes a selection from the menu, the data elements are automatically linked. When a link is created, the locations of the linked data are automatically recorded as part of the data element.

The tools provided by APSAuthor greatly simplify the writer's task. He or she does not have to keep track of the location of the data elements, nor enter the complex codes required to index the data for later extraction from the data base. The writer can focus on creating complete and accurate technical data. The writer never has to worry about determining font sizes, positioning data on the screen, or making color choices. The technical writer need be concerned only with maintenance instructions and complete identification of supporting material.

Presentation Subsystem APSPresent

APSPresent is a program written to retrieve technical data from the APS relational data base and present it to technicians for flight line maintenance. It is a flexible tool that AFHRL implemented to evaluate the relationship of selected functions and screen interfaces with the overall acceptance by maintenance technicians, as well as the benefits of electronic maintenance aids to the maintenance community. It also allows researchers to evaluate the validity of the APS data base design and to develop guidelines describing the best methods to construct and author technical data using APSAuthor.

One of the objectives of the APS was to demonstrate that neutral data can be presented on a variety of different computer systems without modification to the data. To meet this objective, the APSPresent was designed to be very flexible. This was accomplished by a modular software design and the use of a common programming language (C). The software can be adapted for use on other hardware systems by modifying the appropriate modules to incorporate the relevant features of the new system (e.g., screen size, shape, resolution) and any special formatting rules to govern presentation of the data. Versions of APSPresent have been developed for the PCMAS I, PCMAS II, Sun workstation, and MSDOS-based personal computers.

APSPresent retrieves data from the APS relational data base and, basing its decision on the content of the information, dynamically decides how to display the data. The rules used are based upon the results of previous AFHRL research.

The first task of APSPresent is to allow the user to select information to be displayed. To do this, APSPresent must evaluate the user's answers to questions, consider his/her level of expertise, cross-reference the weapon configuration, and bring up the correct version. The program must also know what steps have been seen by the technician. APSPresent can display the next bit of information or what was previously seen, based on track and configuration attributes. APSPresent can also create a menu for the table of contents in order to allow the technician access to any available procedure.

Once a selection has been made, APSPresent must decide how to display the information. Functional specifications and formatting rules developed by human factors engineers are used to assemble and present the interactive technical maintenance information.

Other presentation programs could read the same data base and display the data in a completely different way, based upon entirely different rules. With this type of presentation system, the data need not change as the presentation rules change.

Portable Maintenance Aid (PMA)

A major element of the overall IMIS-DD program is a small portable computer capable of presenting text and complex graphics to the aircraft maintenance technician. Two prototype portable computers were designed specifically for use in research to develop techniques for automated presentation of technical information for use on the flight line. They were PCMAS I and the preplanned product improvement version, PCMAS II. The PCMAS II was adopted as the PMA for the IMIS-DD project. PCMAS I and PCMAS II are described briefly below.

PCMAS I

PCMAS I was AFHRL's initial in-house attempt at designing a portable computer to present automated technical data to maintenance technicians in an on-equipment environment. It served as a research tool for testing the various hardware and software aspects important to the full IMIS development. It helped establish information requirements for an operational portable system. PCMAS I was based upon an earlier design developed by Boeing Military Airplane Company under contract with AFHRL.

PCMAS I features the Motorola 68010 microprocessor with 2.5 megabytes of internal memory and a removable memory cartridge of 1 megabyte of non-volatile memory. It uses an electroluminescent display with high resolution (72 dots per inch). It has the capability to run on an external battery pack, aircraft power, or standard 110V AC power. Two ports allow the device to interface with peripherals in the shop (RS-232) and the MIL-STD-1553 aircraft data bus. PCMAS I uses the UNIX operating system. It also has the capability to present multiple windows of data.

PCMAS I was used in a preliminary test to demonstrate the use of a portable computer for presenting technical information to maintenance personnel. A small sample of technical data was developed for the F-16 Chaff/Flare Dispenser System. Technicians at MacDill AFB, Florida, used the technical data on PCMAS I to perform a checkout task on the system. Test results indicated the technicians could perform maintenance effectively using the system. However, the system required approximately 10 seconds to present a frame of graphics and text. This was judged to be too slow in presenting instructions to satisfactorily support maintenance operations. Technicians participating in the study had a positive reaction to the system but indicated that it was too slow for use in their regular work. Several other weaknesses were identified: (a) The battery capacity was inadequate (maximum of 1 hour), (b) the display was not readable in direct sunlight, and (c) the capacity of the memory cartridge was very limited.

PCMAS II

PCMAS II was developed to provide a system without the problems identified in PCMAS I. PCMAS II was used as the PMA for the IMIS-DD project (see Figure 4). It was fabricated

from an AFHRL design based on the Motorola 68020 microprocessor. It has up to 7 megabytes of memory (4 megabytes of internal memory and 3 megabytes from a non-volatile removable cartridge). The operating system is OS-9, a single-user ROM version of UNIX, which offers the functional requirements needed without the software overhead costs of the full implementation of multiuser UNIX. Power requirements were greatly reduced by using a Liquid Crystal Display (LCD) active matrix screen instead of an electroluminescent display. The LCD active matrix screen gives high resolution (81 dots per inch) at one-tenth the power requirements of the PCMAS I screen. Further power reductions come from the use of Complementary Metal Oxide Semiconductor (CMOS) circuitry. In addition, the LCD display is readable under all lighting conditions as it is equipped with a backlight that the user can switch on as needed.



Figure 4. PMA used for IMIS Diagnostics Demonstration.

To reduce the number and size of the circuit boards inside the unit, surface mount technology was used in about 65% of the circuitry. Integrated circuit chips commonly come in a dual in-line package requiring mounting through both sides of a printed circuit board. The smaller surface mount chips require mounting on one side only, leaving the second side available for additional computer chip logic.

III. METHOD

Accomplishing the goals of the IMIS-DD project required the coordinated performance of several complex tasks. The first task was to select the testbed system. Selection of the testbed was necessary in order to begin work in other areas. Once this was completed, work began on the MIL-STD-1553 data bus interface, technical data development, and modification of the APS presentation software to incorporate IMIS-DM and human computer interface requirements. In addition, evaluation procedures were developed, test problems were selected, and an evaluation plan was prepared. Each of these activities is described below.

Testbed Selection

To achieve the goals of the IMIS-DD project, it was necessary to select an aircraft subsystem to serve as a testbed for use in testing the IMIS-DD capabilities. The testbed system needed to meet the following criteria:

1. Be on an aircraft which is equipped with a MIL-STD-1553 data bus that is controllable from an external device, and maintains a digital record that can be downloaded of failures which occur in flight.
2. Be accessible through the aircraft's data bus.
3. Be sufficiently complex to provide a thorough test of the IMIS-DM capabilities.
4. Be sufficiently simple to permit the development of a complete set of diagnostic and technical data with available resources and within the program schedule.

The F-16 aircraft's FCR system was selected as the testbed for the demonstration for several reasons. First, the F-16 is equipped with a MIL-STD-1553 data bus that can be controlled from an external device. The operational capability upgrade (OCU) version of the F-16 has an external connection located near the right wing which could be used for connecting the portable computer to the aircraft. Second, the OCU version is fitted with a data transfer unit (DTU) which contains a record of the failures that have occurred on the aircraft during flight. This fulfills the requirement to download maintenance data directly from the aircraft. The FCR system was selected from the F-16 systems accessed from the data bus because it is moderately complex and would provide a fair test of the IMIS-DM capabilities. Also, it was judged that technical data for the system could be developed with the available project resources. In addition, the FCR is on the "bad actor" list due to its many maintenance problems. The FCR's bad actor status would provide a challenge for the IMIS-DM and provide face validity for the evaluation.

Development of Diagnostic and Maintenance Data

Two types of data were created for the demonstration: (a) the diagnostic data and (b) non-diagnostic data (test procedures, removal instructions, etc.). The diagnostic data base consists primarily of symptoms, tests, faults, and rectifications. These were entered into the data base using APS in the table form needed by the IMIS-DM software. The non-diagnostic data base consists of the text and graphic materials necessary to perform various tasks such as directions to open a hatch cover and remove an LRU. This material was also authored using the APS.

The authoring task gathered raw data from the following sources:

1. Technical Manual TO 1F-16A-2-94FI-00-1, Fault Isolation Weapons System (USAF, 1987). This TO is commonly called the 94FI by the maintenance technicians.
2. The set of Job Guides referenced by the 94FI.
3. Subject-matter experts, General Dynamics Fort Worth (GDFW) engineers, Air Force technicians of the 388th Tactical Fighter Wing (TFW) at Hill AFB, Utah, and the 31st Aircraft Generation Squadron (AGS) at Homestead AFB.

The fault isolation manual (94FI) is a three-volume set, 800 pages each, containing diagnostic data for all 10 of the F-16 avionics subsystems. The data pertaining to the FCR consist of approximately 500 pages of text, tables, line drawings of various views of the aircraft and equipment, and schematics for the inter-LRU wiring.

Each subsystem section is divided into two major parts: (a) a fault matrix and narrative relating fault codes from the aircraft to instructions for removing and replacing the faulty LRU, and (b) a set of wiring diagrams and schematics. Normally, the matrix and narrative are used to

resolve the failure to an LRU or to a group of components; the wiring diagrams and schematics are used when the matrix and narrative fail to lead to a correct resolution of the problem.

Initially, the creation of the data base seemed to be simply a matter of transposing the fault matrix and narrative text into a form suitable for use by the IMIS-DM and presentation by APS. However, it became apparent that the fault matrix is structured differently than what is required for MDAS and APS. For example, many logical loops are written into the text which a human might be expected to "read through" and continue with the task, but MDAS could not. To implement the same logic under MDAS required that these loops be pulled apart and reassembled without the inconsistencies.

It was assumed the level of detail contained in the text was sufficient to create the "novice track" and that the "expert track" could then be a condensation of the more complete novice track. However, the level of detail in the data for the diagnostic presentation is inconsistent, leaning heavily toward the expert track. When more detail was needed to fill in for the novice track, a detailed analysis of the subsystem was conducted to obtain the necessary information.

As in the fault isolation manual, the Job Guides (JGs) contained logical inconsistencies a human reader might not notice but which had to be resolved for presentation on the PMA. For example, because the JGs were written as general directions for tasks called for in the 94FI, they had to be written in general form. If an aircraft panel required removal, the JG gave directions to remove it. However, directions to remove that same panel might have already been given in the 94FI instructions, resulting in a literal translation of the direction to remove the same panel twice. This type of problem caused great difficulty in creating the data base.

The IMIS-DM software requires a great deal of information to properly analyze the malfunctions encountered. These data were created for IMIS-DD using features of the APS to enter the data into a series of 18 tables. Six of these tables contain information about basic aircraft element systems, symptoms, tests, rectifications, faults, and access groups. Five tables define the mapping among elements of the basic tables. The remaining tables define the operation on the MIL-STD-1553 bus connection to the aircraft.

The 18 data tables constructed were as follows:

1. System Table - The System Table contains a unique system identifier and a short text field that defines the system. For example, FCR would be the system, and the description would be "Fire Control Radar."
2. Symptoms Table - This table identifies and describes symptoms to be diagnosed that can be either observed by the pilot or recorded in the Maintenance Fault List (MFL) on the data transfer unit. Each possible symptom that can be diagnosed is entered in this table. It contains three columns: (a) Symptom ID, (b) Description, and (c) Intermittent ID. The Symptom ID is a simple 6-digit alphanumeric code similar to an MFL that defines the symptom (e.g., SMS-001). The second column, "Description," contains a text description of the symptom; the last column, "Intermittent," indicates the symptom has been designated as either intermittent or not intermittent. An intermittent symptom is a failure indication that occurs during aircraft operation but cannot be duplicated or noticed during maintenance. Possible values for this field are Y (yes) or N (no).
3. Tests Table - This table identifies and describes tests that are used to check the status of the potential faults on the aircraft. It identifies the rectification action and contains a description of the test, the number of possible outcomes, and the time required.

4. Rectification Table - This table identifies and describes rectifications that are used to correct the potential faults on the aircraft. It identifies the rectifications, the repair level, the Mean Time Between Failure (MTBF), and the location of the text data.
5. Faults Table - The Faults Table identifies the potential faults that require rectification. It identifies each fault and contains a text description of the fault and its MTBF.
6. Access Groups Table - This table describes the doors, panels, and skins on the aircraft that must be opened or removed to perform maintenance. It also contains the time needed for each operation.
7. System: Mappings Table - This table associates symptoms, tests, rectifications, faults, and access groups of each system. Each field either holds a unique identifier or is blank. Each System, Symptoms, Tests, Rectification, Faults, and Access Group table has a corresponding identifier in the basic data tables, and vice versa. For example, no fault identifier can be listed in the System Mappings Table and not in the Faults Table; nor can a fault identifier be listed in the Faults Table and not in the System Mappings Table.
8. Access Group Mappings Table - This table lists all the tests and rectifications of each access group. It relates access groups to tests and rectifications in a manner similar to the System Mappings Table. Each field either holds a unique identifier or is blank. Each identifier must be unique, not only within its own group but among all groups. Each test and rectification must have a corresponding identifier in the basic data tables, and vice versa. For example, no test identifier can be listed in the Access Group Mappings Table and not in the Tests Table.
9. Symptoms-to-Faults Table - This table lists the implicated faults of each symptom, as well as the relative probability of each fault.
10. Tests-to-Faults Table - The Tests-to-Faults Table lists the implicated faults of each test. It contains the test ID, outcome indicator, and fault identifier.
11. Rectifications-to-Faults Table - The Rectifications-to-Faults table lists the implicated faults of each rectification.
12. Configurations Table - This table is used to control testing of the various configurations of the weapon system under test. It describes the configuration item (radio, etc.), the various configurations of the item, the associated LRUs involved, and the valid symptoms.
13. Criticalities Table - This table identifies mission critical configurations to be used with the Criticalities Mappings Table.
14. Criticalities Mappings Table - This table identifies and cross-references mission critical configurations to the faults.
15. Test Equipment Table - This table identifies special equipment used during maintenance.
16. Equipment Mappings Table - This table maps the equipment used to the tests that require the equipment.
17. Automatic Test Command Table - This table is used to identify those tests which can be performed automatically (using the BIT on the weapon system) and contains associated parameters required to obtain the test results over the MIL-STD-1553 data bus.

18. 1553 Command Masks Table - This table contains a series of masks needed to transmit the 1553 data bus commands to the subsystem under test.

Test Problem Selection

During the weeks preceding the formal demonstration, the list of proposed faults (see Appendix A) was examined to verify which faults were feasible to simulate and, of those, which were adequately treated by the MDAS data base. Because the demonstration was not planned to be a rigorous, carefully controlled formal experiment, and because the data base was not 100% complete,⁴ it was necessary to select a set of faults for which the data base contained sufficient guidance to lead the subjects through to complete solutions of troubleshooting problems.

After a detailed review of the original list of proposed faults, a set of six was selected for the 2-week demonstration. A scenario was developed for each demonstration problem. The scenarios included:

1. a statement of the means by which the demonstration team could physically simulate the fault in the aircraft (broken cable, bad relay, etc.).
2. the MFL number reported by the aircraft's BIT following insertion of the bad component.
3. a rank-ordered list of the "top five" actions recommended by the IMIS-DM to begin troubleshooting the reported MFL.
4. a listing of the steps the subject would be expected to follow if he/she accepts all of the computer's recommendations.

The six problems selected for use in the evaluation, along with their corresponding MFL numbers, are shown in Table 2.

Two additional problems were planned. Each problem was a combination of two of the faults listed above inserted into the aircraft at the same time. The first combined MFLs 033 and 595; the second combined MFLs 340 and 595. The IMIS-DM resolved these multiple (but independent) faults by sequentially diagnosing them, having them fixed, and rerunning the aircraft's BIT to see if any faults remained.⁵

⁴ Diagnostic data for all known faults were included in the data base for all known faults. However, all required supporting data (job guides, graphics, etc.) were not available for some faults.

⁵ The 033/595 fault was the fourth problem tackled by the first pair of subjects. It involved opening a waveguide (the simulated 033 fault) and resulted in the need to conduct a waveguide pressurization test before the task could be considered complete. A problem arose with this procedure; the waveguide pressurization tester that was immediately available within the Aircraft Maintenance Unit (AMU) for support of the demonstration was not the kind for which the IMIS-DM data base procedure was written. A further problem was that the small ultrasonic leak tester to be used in conjunction with the pressurization test appeared not to be working properly. These two difficulties made the use of the 033 problem, either by itself or combined with MFL 595, undesirable for the demonstration because the subjects were unable to conduct a reliable pressurization test. The study team elected to discontinue the use of either problem containing MFL 033.

Table 2 Simulation of Faults

MFL	How Simulated
033	Open the Schrader valve at the LPRF (simulates a leak in the waveguide)
319	Disconnect the hardline cable between the transmitter and the LPRF
340	Insert a bad K1 relay or pop circuit breaker
400	Install a dummy cable at the DSP or LPRF
572	Disconnect the throttle grip cannon plug (simulates a bad throttle-grip)
595	Install a dummy cable between the LPRF and the Fire Control Computer (FCC)

Evaluation Approach

The IMIS diagnostic capability was evaluated by having Air Force technicians at Homestead AFB, Florida, use the PMA and the IMIS-DM to isolate faults inserted into the FCR on the F-16 aircraft. Their performance was monitored by an experienced observer. After the problems were executed, the technicians completed a questionnaire designed to obtain their reactions to using the system and to solicit suggestions for improving the system.

Subjects

The subjects used in the demonstration were personnel provided by the 308th and 309th Aircraft Maintenance Units (AMUs) of the 31st Tactical Fighter Wing at Homestead AFB, Florida. Twelve subjects were used over the 2-week demonstration period that began on Monday, 8 May 1989, and ended on Friday, 19 May 1989.

Selected biographical information was collected from each of the subjects. In addition to rank and Air Force Specialty Code (AFSC), each subject was asked to report the length of time he had been in the Air Force, in his present specialty, and in the Tactical Air Command (TAC). He was also asked how much time he had spent working on the F-16 A, B, C, and D models, how much time on the F-16 radar system, and how much time on other aircraft besides the F-16. The career status and biographical information for the subjects are summarized in Tables 3 and 4, respectively. All 12 subjects possessed the 452X2 AFSC. Eight reported being in the 452X2A Air Force Specialty (AFS) (the A suffix denotes "A-shoppers," whose responsibilities include the fire control radar); two of the subjects reported being in the 452X2B AFS (the B suffix denotes

Table 3 Specialties and Skill Levels of Demonstration Subjects

Subject No.	Specialty Code			Skill Level	Rank
	452X2A	452X2B	452X2		
1	*			3	SSgt
2		*		5	SRA
3		*		5	A1C
4	*			5	A1C
5	*			3	A1C
6	*			3	Sgt
7	*			3	SRA
8	*			3	A1C
9	*			3	Amn
10		*		3	A1C
11	*			3	A1C
12			*	7	MSgt

Table 4 Biographical Data for Demonstration Subjects

Subject Number	Time (In Months)					
	AF	Specialty	TAC	A/B	C/D	F-16 Radar
1	66	12	48	12	0	12
2	36	36	2	2	26	28
3	27	27	27	27	0	27
4	36	36	36	36	0	36
5	13	13	13	13	0	13
6	53	5	5	18	12	5
7	48	36	48	12	0	12
8	17	17	17	17	0	17
9	14	14	14	14	0	14
10	14	14	14	14	0	14
11	18	18	18	18	0	18
12	186	120	186	114	6	120
Mean	44.0	29.0	35.67	24.75	3.67	26.3

"B-shoppers," who deal with the flight control system); two reported no suffix, describing themselves only as "avionics specialists." Eight of the technicians were classified at the 3 skill-level, three at the 5 skill-level, and one at the 7 skill-level. Only three subjects reported experience with other aircraft types. Subject number 6 reported 18 months with T-37s; subject number 7 reported 24 months with F-4s; and subject number 12 reported 65 months with RF-4Cs, T-33s, and T-39s.

Questionnaires

Two questionnaires were developed for gathering participants' subjective impressions (see Appendix B). The first, called "IMIS-DD Task Debriefing" (see Appendix B), was a brief series of questions to be administered upon completion of each troubleshooting problem, while details of that problem were fresh in the subject's mind. The second, called "IMIS-DD User Evaluation Questionnaire" (see Appendix B), was designed to elicit some summary impressions from each subject upon completion of all of his assigned problems.

The debriefing form was intended to explore any difficulties that the subject might have experienced during the performance of each task. The subject was asked to describe these difficulties in as much detail as possible (using the PMA to illustrate them, if necessary), while the task was still fresh in his mind. The form also requested the subject to list the good features of the PMA he had noted during the task, and to give suggestions to improve the PMA hardware or software. Each subject completed the evaluation questionnaire after he had performed all of his assigned problems. The subject was asked to use a 5-point scale to rate some physical features of the system and the information presented by the PMA, and to compare the presentation of data on the PMA with that currently used in paper technical orders (TOs.) The questionnaire also asked open-ended questions to elicit each subject's opinions about the level of detail, likes and dislikes about the PMA, and potential implementation problems. It also requested suggestions the subject might have for improving the PMA.

Procedures

The subjects participated in the study in pairs. The study team generally had access to a given pair of subjects for at least 1 full workday; some subjects were available for approximately 1.5 workdays.

Each pair of subjects began by spending approximately 1 hour in a familiarization/training session with an evaluation team member. This training period generally consisted of an introduction to the IMIS-DD project, a description of the PMA and procedures for its use, a demonstration of most of its available features, and a period of approximately 15 minutes during which the subjects could practice with the PMA.

While the subjects were being introduced to the PMA, other members of the study team (assisted by a technician assigned by the 31st AGS) ran the FCR BIT to verify that the aircraft did not have any faults that would interfere with the planned test. The team then inserted the first chosen fault and ran the BIT again to confirm that the proper MFL fault was reported.

When the subjects arrived at the test hangar following the training period, they were given a PMA with the memory module installed and were told to begin troubleshooting the aircraft. If the particular problem involved pilot-reported faults in addition to MFLs reported by the BIT, the subjects were given such information verbally before beginning to troubleshoot.

At various points during each problem, electrical power had to be applied to the aircraft to allow it to run the BIT on the radar. Because the F-15 is not designed to allow an external device such as the PMA to run the BIT entirely from outside the airplane, it was necessary for one of the subjects to sit in the cockpit during the operation of the BIT to configure switches in a way that allowed the PMA to download fault information. The other subject stayed on the ground and read a PMA-displayed checklist of switch settings to the technician in the cockpit. During these periods, the noise created by a turbine-powered generator and an air conditioning unit made it necessary for the subjects to communicate with each other using the aircraft's intercom via noise-cancelling headsets and microphones, just as they would on the flight line. One of the study team members, the "designated observer," also used the intercom at the same time to monitor the subjects' interactions and to be available to answer questions. Other study team members and occasional visitors/observers were also in the area during the performance of most tasks, but only the observer with the headset could monitor what the subjects said while the generator was running.

Once a pair of subjects had begun a task, they were allowed to proceed on their own without interruption, unless the designated observer noticed that they had done (or were about to do) something completely inappropriate. The designated observer was allowed to answer questions that the subjects asked, but he tried to provide as little information as possible, if he believed the subjects could answer their own questions using the PMA. The subjects needed occasional prompts to help them recall the PMA features they clearly did not remember from the brief familiarization/training session.

Subjects proceeded through a task, interacted with the PMA (see Figure 5), performed tests, and ran the BIT until they had found and corrected the fault (and confirmed that fact via the BIT). Upon completion of each task, the subjects accompanied the designated observer to the break room or to a quiet corner of the hangar to go through the task debriefing form. The observer took notes during each task on anything the subjects were observed doing that deviated from the "computer-recommended" path. These notes were used to stimulate discussion during the debriefing. In some cases, the subjects were unable to add anything to what was already contained in the observer's notes. In other cases, the subjects simply did not have any problems to report, and no new ideas about the PMA had occurred to them since the previous task. Consequently, the debriefing form was empty for some tasks.

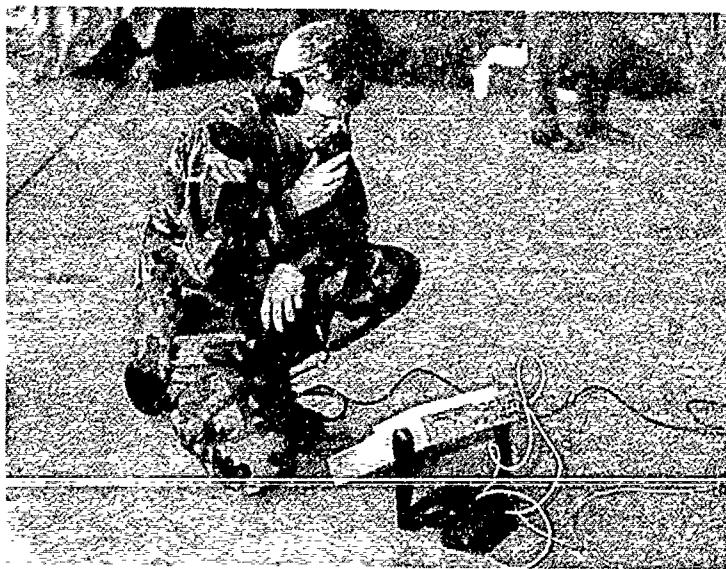


Figure 5. Technician using PMA during demonstration.

The notes maintained by the observer during the performance of each task included the problem number; identification of the subjects performing the task; the date, time, and location of the task performance; and start and finish times of the task. As the task progressed, the observer noted deviations from the computer-recommended path, and also any optional information the subjects accessed during the task. When the subjects encountered difficulties, the observer noted them and tried to describe the nature of the problem.

Final Debriefing

On the final day of the 2-week demonstration, 8 of the 12 subjects joined the research team for a general, informal debriefing session held in a large meeting room at the base recreation center. Most of the discussion was captured on videotape. During this session, comments and observations were made by both subjects and members of the demonstration team. There was no particular order to the topics and the discussion tended to be free and open. Some of the topics covered during this session had not been covered in the questionnaires. The principal reason for holding the informal session was to give the subjects time to reflect on the experience several days following their participation.

IV. RESULTS

The 12 subjects (6 pairs) performed a total of 21 troubleshooting problems, with an average of three tasks for each pair. All troubleshooting problems were successfully solved. Specific observations, along with the results of the questionnaires and briefings, are summarized below.

Performance Data

Table 5 shows which problems were assigned to the subject pairs and the order in which the problems were presented. Performance times for each problem are given in Table 6. As the performance of a given task progressed, the observer took notes and answered questions as necessary, but tried not to intrude into the subject's process of using the PMA and performing tests and rectifications on the aircraft. In general, the subjects did not appear to be uneasy with the observer looking over their shoulders, nor did the presence of other people in the immediate area appear to be particularly disruptive.

Table 6 illustrates that there was relatively little variance in the performance times for all subject pairs who performed problems 319, 400, and 572. The time variances for the other problems were due to the order in which the tasks were presented, and the level of familiarity with the FCR system and its related tasks. Specific observations for each problem are given below. Appendix A lists the procedure for simulating each fault on the aircraft.

Performance Observations

Problem 319. This problem simulated a broken hard line between the transmitter and the LPRF (low power radio frequency unit). The three subject pairs who worked on this problem were familiar with the procedures for removing and installing these two LRUs, and they all merely glanced at the procedures for accomplishing these tasks.

All of the subjects performed troubleshooting of the fault essentially as the computer recommended. All subjects found the broken hard line promptly. They ran a continuity check, and were then told to assume the line was bad (even though it was not) and to follow the PMA

Table 5 Order of Problem Performance

Subjects	Problem (MFL)							
	033	319	340	400	572	595	033/595	595/340
1&2		3	2			1	4	
3&4			5	1	3	2		4
5&6			2	1	4			3
5&7		1						
7&8								1
9&10		4	1		3			2
11&12			1					2

Table 6 Performance Time in Minutes

Subjects	Problem (MFL)							
	033	319	340	400	572	595	033/595	595/340
1&2		53	56			27	75	
3&4			59	47	60	55		49
5&6			32	49	59			45
5&7		59						
7&8								98
9&10		55	26		65			75
11&12			30					109
Mean		55.7	40.6	48.0	61.3	41.0	75.0	75.2

instructions for its replacement. They performed all of the removal and installation steps except those that required breaking the waveguide and loosening the LRU mount bolts. The observer told them to simulate those steps in order to avoid having to re-torque the bolts and run a waveguide pressurization test. The waveguide pressurization test could not be done because the only available ultrasonic leak checker was broken.

Subjects 1 and 2 said they felt a bit slowed down by the PMA in contrast to the Job Guides, pointing out that "You can go a lot faster when you don't have to follow the procedure step by step. We know the procedure." The implication was that if they had been "using" a Job Guide Manual, they would have opened it but not looked at it for these procedural steps.

Subjects 9 and 10 invariably paged past continued notes and cautions (longer than one screen), rather than using the down arrow to see the rest of the text because they had already read them so many times in the manuals. These individuals were quite puzzled by the graphics that supported the replacement of the broken hard line. One reported he had no idea what the graphic of the forward bulkhead was supposed to represent. The graphic was small and essentially illegible. Despite the poor graphic, they were able to proceed and complete the task essentially "by the book." Subjects 5 and 7 had no difficulties and made no deviations from the computer's recommended path.

Problem 340. When presented by itself, this problem was created twice by installing a bad relay and three times simply by opening a circuit breaker. Checking the circuit breaker is the first action recommended by the computer in response to this MFL number; so, finding the problem tended to be much quicker when the circuit breaker was the only problem. This is confirmed by Table 6, which shows that the first two pairs of subjects, who had the bad-relay fault, took roughly twice as long to complete the problem as did the other three pairs of subjects, who had only a popped breaker.

Subjects 1 and 2 essentially followed the computer-recommended procedure, including replacement of the transmitter, which is a recommendation preceding the relay check. They later said that despite the outcome (the problem was really the relay), they liked the logic of the computer's recommendation, and that they probably would have replaced the transmitter out on the flight line if they had been troubleshooting on their own, despite the ease of checking the relay because "relays never fail."

Subjects 3 and 4 looked at their options several times when they reached the point at which the computer recommended replacing the transmitter. They ultimately decided to go for the relay on the grounds that they had noticed it had a blue plastic case, while all the others had aluminum cases. They guessed the demonstration team was more likely to have stuck in a bad relay than to have installed a bad transmitter. Their time is somewhat inflated because they dropped a small flat washer that was part of the relay's attaching hardware. The entire team spent approximately 7 minutes crawling around on the hangar floor searching for it. The remainder of the task went satisfactorily.

The last three subject pairs had only to deal with the opened circuit breaker. The part of the PMA presentation that deals with checking the breaker is quite clumsy, especially for an experienced technician. All of the subjects knew where the panel was, how to open the panel, and how to check a breaker. However, the task required them to step through the procedure for opening the panel; then to follow the procedure for checking the breaker and answer the question, "Is the breaker tripped?"; and then to do the procedure for resetting the breaker. For the more experienced person, such a procedure probably should be streamlined by telling the technician to open the panel, check the breaker and reset it if necessary (in this case, that is always the next step if it is tripped), and asking him whether he had to reset it or not. The answer to that question would satisfy the diagnostic process, and the whole thing could be presented in a single step. Subjects 9 and 10 commented that this kind of clumsiness could induce people to use the PMA improperly. They said, "Experienced people know lots of procedures. They will wind up doing the job, then going back through the computer just to get the data into CAMS (Core Automated Maintenance System)." This problem is one that could easily occur with a neutral data base because the formatting instructions are not part of the data but, instead, are in the presentation system. The technical data author does not need to know what procedures may occur given the

result of another; the presentation system, along with the diagnostics, determines the next procedure to be presented.

Before Subjects 11 and 12 ran the final BIT check on this task, the subject operating the PMA read the switch settings to himself, but forgot to tell the subject in the cockpit to recycle the radar; so, they got the same fault code again. The observer had to point out the omission. They corrected it and the next BIT passed.

Problem 400. This problem was created by installing a dummy cable between the LPRF and the DSP (digital signal processor). Subjects 3 and 4 missed the fact that the first "Input Conditions" screen before the BIT listed "power on the aircraft." There was no procedure automatically presented by the PMA for turning on the generator; so, they neglected to do it. When this omission was pointed out to them, they tried to back up to the input conditions screen to confirm the condition for themselves, but the PMA did not return to that screen (a conceptual problem with the way the BACK function was implemented). The session was restarted in order to step through to that point again.

This difficulty is the result of an inability to include every task available for the FCR system. Several of the tasks used in the demonstration have input conditions that include a couple of open panels and power-on (or power-off) of the aircraft; subsequent screens present procedures for opening the panels, but never for starting or stopping the external generator. This data omission had not been discovered until the demonstration was underway. When the problem was first noticed, the team began to point out the problem during the familiarization/training session. This helped but it did not completely fix the problem; several individuals still made the same error even after having it pointed out during training.

Subjects 5 and 6, whose previous experience did not include troubleshooting wiring problems, had some difficulty in using the correct nomenclature to identify connectors. When they had removed two incorrect connectors, the observer suggested that they try the more-detailed track (using the "M/L" key) to see if the additional detail and graphics would help them. They switched tracks and were then able to identify the appropriate connectors. They managed to identify the faulty cable, but they proceeded on to the BIT check without going through the procedure to repair the cable because they hit NEXT too soon and were confused about how to "back track." The observer helped them to back track.

Problem 572. This problem was created by disconnecting a cannon plug in the cable leading to the throttle grip. All three pairs of subjects followed the computer's recommended path to the point of confirming a bad continuity check, but all balked at the computer's recommended next step of replacing the throttle grip. Each of the subject pairs had at this point performed two or three previous problems using the PMA, and all were eager to "second-guess" the computer and go after something they believed the demonstration team was more likely to have done to "bug" the aircraft, such as another wiring problem (which happened to be the computer's second recommendation at that point). Subjects 9 and 10 explored nearly every bit of optional information available, looking for a justification for their desire to avoid changing the throttle grip; the other subjects simply decided that they didn't want to change it, without agonizing over the decision to countermand the computer's suggestion. All subjects ultimately chose the option of repairing the wiring.

There was no graphic or procedural assistance available within the iMiS-DD data base to support locating and identifying the other end of the cable they wanted to repair. At this point, the observers gave the subjects a paper copy of a graphic that had been created from the TO showing the location of the other end of the cable. The subjects used this illustration to guide them to the other connector. Subjects 9 and 10 noticed a problem, but by the time they had selected the wiring repair option, they no longer remembered which three wires had been checked for continuity (and

were therefore candidates for repair). They were no longer able to back track to the screen that contained the continuity check, which identified those wires. If they had actually had to repair the cable, they would not have known how to retrieve that information from the PMA.

During this and most other tasks, several individuals had a problem interpreting the screen that immediately follows each BIT. When the BIT returns one or more MFL numbers, those numbers are reported on one line of the screen; MFLs (if any) that were recorded during formal debriefing of the pilot are presented on lines below. When the technicians have successfully repaired a fault and BIT finally returns no MFLs, the PMA concludes that the reported faults have been found. It simply leaves an empty line on the screen where the BIT-returned MFLs were initially displayed, and it continues to show the pilot-reported MFLs below on their original line (this has since been corrected; instead of being blank, the word "none" is now displayed). Even when the BIT shows no faults, a user who is not a careful reader can easily overlook the blank line and think the screen is telling him there is still a fault being reported by the system. After this problem was first noted, the demonstration team began to point out the correct interpretation of the screen during familiarization/training; but some individuals still became confused during the task performance when they reached this screen.

Problem 595. This problem is produced by installing a dummy cable between the FCC and the LPRF. Only two subject pairs did this problem by itself; all other subject pairs encountering problem 595 saw this fault in combination with problem 340.

It was on this problem that a conceptual disconnect was discovered between the two levels-of-detail tracks. At the point in the "LESS" (less detailed) procedure where the user is told to do a visual inspection of a cable and repair it as necessary, if he selects the "MORE" track, he gets detailed information about repair, but nothing on inspection which should precede repair. This is another example of where the data available to the authors were not complete. Subjects 1 and 2 actually began hunting for tools to cut a connector off (part of "repair") before inspecting the cable thoroughly enough to discover that it was a dummy because that is what the procedure told them.

Subjects 3 and 4 took substantially longer to do this task than did Subjects 1 and 2. They did not make any major mistakes; but early in the task, a senior officer stopped by to observe. His presence appeared to unnerve the subject using the PMA. The subject began to go past some screens without confirming switch settings with his partner in the cockpit. He began to make errors in reading portions of procedures aloud, and repeated several steps two and three times, just to get the words right.

At one point, a procedural step asked if the cable from the PMA to the aircraft was connected. The subject was puzzled. He had disconnected the cable earlier in order to move the PMA; so, it was in fact disconnected. But, he suspected that the reason for the question was really to get him to connect the cable if necessary, even though it did not say so. He finally asked the observer, who told him his interpretation was correct -- he should connect the cable and continue. This highlights the need for the TO author to think carefully about the reason for an action, before deciding how to present an instruction.

Problems 033 and 595. Problem 033 was produced by opening a valve in the waveguide, simulating a leaking waveguide. As mentioned earlier, problems 033 and 595 combined were presented to one pair of subjects; but because of problems with a waveguide pressurization tester and an ultrasonic leak detector, the study team decided that 033 would not be used again, either alone or in combination. Also, it was decided for any other tasks requiring the waveguide to be disconnected that the team would simulate the portions of the task that would create the need for a pressurization test.

Subjects 1 and 2 did this combined problem. Except for the difficulties with the pressurization tester and the problem mentioned above of losing information on inspection of a cable when switching to the more detailed track, they performed smoothly and found both faults. They were surprised to discover a fault still remained after they fixed the first one, but they pressed on with the PMA and found the second one.

During one of the BITs for this task, the subject who did the switch-setting in the cockpit took the PMA with him and held it on his lap to see if he could accomplish the entire test by himself. It turned out to be possible, but uncomfortable. The PMA procedure was easy to read and the illustrations of switch locations were judged to be adequate, but the battery pack was too bulky to be handled easily on one's lap in the cockpit. The subject had to move the battery pack back and forth in order to reach necessary cockpit switches, and it was too bulky to allow one person to comfortably carry it up the ladder and enter the cockpit safely. Another person had to hand the PMA to the subject once he was safely seated in the cockpit. It should be noted that one of the ultimate goals of IMIS is to obviate the need for the maintenance person to enter the cockpit at all in order to run BIT; so, this apparent shortcoming of the PMA is moot.

Problems 595 and 340. This combination of problems was handled in a relatively straightforward manner by all subject pairs. The fact that it contained multiple faults was never initially known to subjects when they began. Once they repaired the first fault and ran the BIT, a new MFL appeared; and they simply continued to troubleshoot until they cleared the second fault.

Subjects 3 and 4 found the dummy cable (the 595 fault) essentially "by the book." During a continuity check while working on the 340 fault, they misread a pin number on a power-panel connector and reported a bad result (it was really good on the correct pin). The observer stopped them and reset the PMA to the continuity check again, which they reported correctly this time. Several subjects had trouble with this particular connector. It is large and has a confusing pin-numbering pattern that makes it easy for a technician to err in selecting the proper pin to check.

These two subjects recognized the bad relay from the day before (the blue plastic case), and they decided to replace it instead of the transmitter, which was the computer's first recommendation. This cleared the fault and they finished the problem without further incident.

Subjects 5 and 6 found both problems essentially by the book, except they chose to replace the relay instead of the transmitter. They had not seen the blue relay before, but they admitted they guessed the demonstration team was more likely to have bugged a relay than a transmitter. They did say, though, that on the flight line in a similar situation, they would have "slaved," or cannibalized, a transmitter (swapped the suspected transmitter with a known good one from another aircraft on the line), which was the number one recommendation. Their only procedural error was resetting a circuit breaker before the procedure told them to (as discussed earlier).

For the most part, Subjects 7 and 8 went through these problems smoothly. One of the subjects, however, was completely unskilled in the use of a multimeter for continuity checks. He confused the conditions of "open" and "short," and would have responded incorrectly to the question about continuity ("Is continuity present ... ?") if the observer had not interrupted. He also left a connector disconnected after the continuity check, but the other subject caught it before they ran the BIT.

Subjects 9 and 10 both were relatively inexperienced with the radar system; neither was familiar with system geography, particularly cable and connector locations. They had considerable difficulty locating specified connectors, even when they switched to the more detailed track. They later complained that the illustrations and diagrams should have had more detail on locating pins on connectors. When they began to work on problem 340, they had a hard time finding the correct pin at the power panel (the same connector which troubled Subjects 3 and 4).

Again, one of the subjects was misled by the question asking if the PMA was connected to the aircraft; he saw that it was not, and simply chose the "no" answer (the author had evidently intended that the user hook up the cable, then answer "yes"). Being unable to back up in the procedure, the observers had to reset the procedure before running the BIT.⁶

When the subjects reached the point where the computer recommended replacing the transmitter, they balked (having come to expect simpler problem solutions from the demonstration team), explored options, and elected to replace the relay instead. Replacement of the relay followed, but the subjects, who had never removed a relay before, believed they did not have the correct-sized socket to remove the attaching nuts. They searched for several minutes before discovering they did, in fact, have the proper socket.

Subjects 11 and 12 did both problems entirely by the book. One of the subjects was much more experienced than the other, who was both inexperienced and a poor reader. The more experienced individual allowed the other to use the PMA and to make nearly all decisions. The PMA user, who was uneasy in the troubleshooting situation, elected to go with all of the computer's recommendations. Apparently, he felt unqualified to second-guess it, and received no advice from his more experienced partner.

The less experienced subject appeared to be mistakenly selecting the "INFO" key instead of the "NEXT" key when he intended to advance to the next step. When asked later about that frequent apparent error, he reported that he had really been searching for a way to "preview" or browse ahead and review a procedure before actually making the commitment to perform it. He was mildly relieved to learn that the reason he had not found that information was that no such feature currently exists.

As described earlier for another subject, when this subject switched to the more detailed track for connector location information during the continuity check, he lost the spot in the procedure where he should have been directed to inspect the cable, and it appeared the PMA was directing him to repair the cable without even checking it. Like several other subjects, he also tended to "jump the gun" at the point of checking the circuit breaker, wanting to do most of the procedural steps before being directed to do them by the PMA.

Task Debriefing

Because the observer's notes tended to cover the nature of most of the problems encountered by the subjects, each debriefing session focused on the subject's general likes and dislikes of the preceding task's performance. The responses are contained in Appendix B.

Questionnaire Results

The questionnaires were administered to subjects after they had finished all of the problems assigned to them. A complete sample questionnaire is presented in Appendix B. The first 21 items were topics on which the subjects were asked to rate the PMA, either by itself or in comparison with paper TOS. Their individual and mean ratings for these items are presented in Table 7.

⁶This problem has since been corrected. Originally it was designed for laboratory demonstration purposes to have the "no" answer produce a "pass" result for the BIT.

The remainder of the questionnaire consisted of open-ended questions with spaces where the subjects could write their responses. Appendix B contains the complete, verbatim response of each subject who responded for each question.

Table 7. Questionnaire Responses

Question	Object Number												Mean
	1	2	3	4	5	6	7	8	9	10	11	12	
1 Location of keys	4	5	3	3	4	5	5	4	3	5	3	3	3.92
2 Spacing of keys	4	5	3	4	4	5	5	4	3	4	3	3	3.92
3 Ease of operating key	4	5	4	4	4	5	5	4	3	3	3	3	3.92
4 Key tactile feedback	3	5	4	4	4	4	4	4	3	4	3	3	3.75
5 Response time	3	5	5	4	3	4	4	4	4	-	4	2	3.82
6 Screen size	3	5	5	4	3	5	5	2	3	3	4	4	3.83
7 White space/clutter	4	5	4	3	4	5	5	2	4	4	4	3	3.92
8 Screen brightness	4	5	5	3	4	5	5	4	4	5	4	3	4.25
9 Screen glare	4	5	5	4	4	4	5	4	3	5	3	3	4.08
10 Large character legibility	4	5	4	3	4	5	5	4	3	5	4	3	4.08
11 Small character legibility	4	5	4	3	4	5	5	4	3	5	4	3	4.08
12 Graphics legibility	3	5	5	2	2	4	4	2	2	1	4	3	3.08
13 Graphics detail	3	4	5	3	2	3	4	2	2	1	4	3	3.00
14 Organization of information	5	5	4	2	3	5	5	4	3	3	3	4	3.83
15 Options menus/function keys	4	4	4	3	3	4	5	4	4	4	2	3	3.67
16 Use of menus/function keys	4	5	5	3	4	5	5	4	4	4	2	3	4.00
17 Adequacy of graphics	3	5	5	3	3	4	4	2	2	1	4	3	3.25
18 Adequacy of information	4	5	2	3	4	4	5	4	3	3	4	3	3.67
19 Time/effort to do task	5	4	5	3	4	5	5	4	3	3	3	5	4.08
20 Time/effort for more detail	5	5	4	3	4	5	5	4	3	3	4	5	4.17
21 Is PCMAS an improvement?	4	4	5	-	3	4	4	4	2	4	4	5	3.91
<u>Overall Mean</u>													3.82

Rating Scale:

- 1 Unsatisfactory
- 2 Marginal
- 3 Satisfactory
- 4 Highly Satisfactory
- 5 Outstanding
- Can't Evaluate (or no response)

Final Debriefing

During the final group meeting (debriefing), the group considered a variety of topics. Topics were introduced and discussed in no particular order for a period of approximately 1 hour. The following issues were raised and discussed.

1. The BACKUP function does not work well.
2. It is not possible to browse through a procedure without having the computer think you have actually performed the procedure.
3. Some graphics are too small. "It's hard to see what plugs are located where."

4. It is too easy to overlook the "More Information Available" message (which indicates that a piece of text is continued but lies off-screen, below or to the right or left). It was suggested that such continued material just be put on the next screen, to be accessed with the NEXT key instead of continuing to risk that it will be overlooked.
5. Detail was weak in some of the graphics; some "looked like etch-a-sketch drawings."
6. Of the extra information keys, some people liked the OPTIONS key best. They liked being able to see their most logical options, instead of going through page after page of the fault isolation manual or such things as their (informal) "flight control trivia" book of historical best options, which have been obtained through conversations with various bases.
7. Some technicians liked the "Failure Probability" information provided by the IMIS-DM. They used it and think it helped with their decision-making.
8. During the study, some subjects based troubleshooting decisions on what kinds of "bugs" they thought the study team might have installed, instead of what the logical solution should have been.
9. Several subjects liked the block diagram showing plausible, maybe, and exonerated components. "I liked the way the block diagram showed what was going on." "The block diagram feature would be valuable for shift changes [to communicate to the next shift what you had done so far, and what you had found out]."
10. Breaking the high-level block diagram into three subdiagrams for the radar "...was the best way to partition the larger block diagrams."
11. The PMA was easier to carry than a bunch of TOs.
12. The data base should have included power-on and power-off procedures to make it consistent with the way other input condition items were treated.
13. The IMIS system must develop some visual indication to the user when pieces of procedures have been revised or updated. The scheme could use vertical bars in the margins like the present paper TOs.
14. Some liked the (simulated) availability of history information from CAMS. They thought it would be very helpful.
15. Some subjects are presently leery of CAMS. The system goes down a lot, and loses some information that people have entered into it.
16. Some technicians want more theory, to back up the computer's recommendations. They want to know "why" something is recommended, rather than just being given a list of functions that particular components perform. Some also mentioned a desire for theory on what functions are being tested during continuity checks.

V. DISCUSSION

The IMIS-DD is simply what it was intended to be: a demonstration of the diagnostic capabilities of the PMA and the IMIS-DM. It was the first of two efforts to validate and test diagnostic concepts for implementation in the IMIS program. The demonstration was an initial proof-of-concept effort to test and refine the concepts and tools necessary to provide the diagnostic capability for the IMIS. As such, it was not intended to be an exhaustive evaluation of the IMIS diagnostic technology; rather, it was intended as a step in the development of this technology. The basic objectives were (a) to verify the validity of the IMIS-DM by testing it under "real-world" conditions, (b) to verify the feasibility of using the IMIS-DM and a portable computer to activate the BIT and directly access system status data via the aircraft's MIL-STD-1553 data bus, (c) to obtain data on the degree to which the technicians were able to solve troubleshooting problems using the system, and (d) to identify ways to improve the system.

Although the limited number of subjects and time available for the demonstration made it impossible to conduct a carefully controlled, experimental study, the basic objectives of the effort were achieved. The demonstration showed that the IMIS-DM does provide an effective diagnostic capability, the PMA and IMIS-DD can activate the aircraft's BIT and download data for use in the diagnostic process, and the technicians can effectively use the PMA and IMIS-DM to solve troubleshooting problems. Many valuable lessons were learned--most in the user interface area.

The IMIS-DM effectively resolved all of the test problems. Although no data were available to compare the diagnostics strategy provided by the IMIS-DM with the strategy provided to the technicians for troubleshooting using the paper TOs, many technicians indicated that the strategy proposed by the system was the same or, in some cases, better than the strategy they would have implemented if they had been working on their own.

The major portion of the information used for the diagnostic data base was taken from the Fault Isolation (FI) and Job Guide Manuals. However, some diagnostic information used by the IMIS-DM was developed by, or through discussions with, maintenance experts. This extra information went beyond the help available in the FIs; so, theoretically, the very least the PMA can do as a performance aid for troubleshooting should be equivalent to the best that the relevant FIs could do. A clear implication is that an individual who is completely dependent on his or her job aid would be able to solve more problems using a PMA than FIs.

The capability to connect the PMA to the MIL-STD-1553 data bus, use the PMA to initiate the aircraft's BIT capability, and utilize the results to guide the diagnostic process was demonstrated. The technicians connected the PMA to the aircraft's MIL-STD-1553 data bus and downloaded fault information, then used the PMA as the single source of diagnostic and procedural information to support troubleshooting. This demonstrated the feasibility of the basic concept; however, the full potential of the concept was not demonstrated in that the F-16 has relatively limited capabilities for accessing data through the MIL-STD-1553 data bus. The available data are limited to results from the BIT in addition to the in-flight failures recorded on the aircraft's DTU. Newer aircraft, such as the F/A-18, have improved data access through the data bus. This will allow a PMA device to access data such as the contents of selected memory locations on aircraft systems for use in the diagnostic process.

Although some problems were encountered, the technicians found the system easy to use. They were able to perform the assigned tasks after only very limited training (about 1 hour). Most of the problems the technicians encountered using the system resulted from inexperience with the system; these difficulties most likely would be overcome with experience. However, several

weaknesses were identified which require correction for the system to be fully satisfactory from the user's point of view.

The most serious user problem was the difficulty the technicians occasionally had in deciding what kind of information they wanted, and how to get it. Another problem arose because current software does not contain a provision for the user to "look ahead" and explore procedures he or she is unsure of and might want to perform. Nor does the software have a pure "backup" function to perform a backward tracing of all screens previously viewed in the current session. Both of these capabilities would have been beneficial as the subjects had a low level of experience with the PMA. Sometimes an inexperienced user feels lost or uneasy, but is not sure whether he or she is really lost. In such cases, being able to look forward in the data base or to step backward and review the session's protocol up to the current point would allow the hesitant user to determine exactly what has been done and where the session is going.

A related problem is the present treatment of the two levels of detail (two-track) feature. As implemented, the two tracks are parallel rather than overlaid, as with "hypertext." Within a task, if a person goes through several steps in one track and then decides to shift to the other track, he or she is sent back to the beginning of the task steps in the previous track. This resetting to the beginning was viewed by the demonstration subjects more as an aberration than a desirable feature. Technicians who attempted to shift levels were generally a bit uneasy when they found themselves at the beginning of the sequence of steps. Suddenly finding themselves at a different point, with a different level of descriptive detail, was somewhat confusing. At best, such a mechanism wastes time while the user reads through the procedure to get back to the step being performed when the decision to shift was made. At worst, it can be so disorienting the user believes he or she has made a mistake and has somehow jumped to another (perhaps inappropriate) task; the user then has to stop completely in order to figure out where he or she is in the procedure.

As with most features of the current implementation, the track-shifting problem would undoubtedly become less of a problem as users accumulated sufficient experience with the device. A track-changing feature permitting a user to shift back and forth between levels without losing his or her place or restarting the procedure would clearly be an improvement; its use would be more intuitive, especially for the inexperienced technician.

Problems were encountered with some of the graphics: (a) some were too small, (b) others did not have enough detail, (c) some were inadequate or had missing callouts, and (d) some necessary graphics were not available. Most of the graphics were legible, but many were not sized to take advantage of available screen space (a small drawing might appear in the lower right corner of an otherwise mostly blank screen), and many suffered from missing or misaligned callouts and leader lines. These problems presented few difficulties to the experienced subjects because these subjects were generally familiar with the objects portrayed and did not really need illustrations to find the objects. Several inexperienced individuals were not helped at all by some of the graphics. It was particularly difficult for people who were inexperienced in troubleshooting wiring problems or uncertain of the system geography to decipher some illustrations showing connector locations. These same people also expressed a desire for additional drawings to help them locate specified pins on large, multi-pin connectors with arcane numbering patterns. Some of the subjects preferring somewhat more detailed graphics complained about the "Etch-a-Sketch" quality of many of the existing graphics. Although graphics taken from technical orders were included in the data base for most procedures, the tight predemonstration schedule had not allowed enough time to develop adequate graphics to support some procedures. One example is the lack of a graphic to show the location of the throttle-grip connector. The Job Guides and FIs provided no graphic support for that procedure either. Thus, the PMA was still no worse than the combination of existing Job Guides and FIs in the guidance it provided. Although most of the technicians were able to "work around" inadequate graphics, the study clearly points to a need for an increased emphasis on developing effective graphics for future tests and demonstrations.

The general reactions of the technicians to using the PMA and IMIS-DM were very positive. They were favorably impressed with the capabilities of the PMA, and most indicated they would use it regularly if given a chance. Some were even more enthusiastic, expressing the wish for some form of the PMA to be fielded much sooner than presently planned. A few wanted to take the device with them, even though they realized its data base covered only the FCR system.

All of the subjects had experience with CAMS. They respected its data base, but strongly disliked its user interface. They readily appreciated the desirability of using a PMA as their single point of interface with CAMS and the base supply system. Without exception, they were very impressed when the PMA presented automatically filled-in CAMS data on the screen at the end of each task.

The PMA computer proved to be an effective research tool for testing the IMIS-DM and evaluating the use of a portable computer to present technical information for on-equipment maintenance. It provided all required capabilities in an efficient manner, and the technicians seemed to like using it. The major complaint was that it is too large and too heavy for convenient use on the flight line. Some technicians also expressed a concern regarding the ability of a computer to withstand the rough treatment it would receive on the flight line. These objections were withdrawn when it was explained that a much smaller version is under development and fielded systems will be small, and ruggedized to withstand the rigors of the flight line.

Conclusions

Much valuable information was gained from the demonstration. The objectives were successfully met, and AFHRL was able to collect constructive feedback to apply to future demonstrations. It was shown that a portable computer could be used for on-equipment maintenance to assist in troubleshooting and repair procedures. The computer was able to integrate diagnostics with technical data, as well as initiate the BIT to gain information for the diagnostics. Some problems exist, as discussed; but overall, the reaction to an IMIS system was extremely positive.

Follow-On Efforts

The lessons learned in the IMIS-DD are being applied in follow-on efforts to refine and test the IMIS-DM technology.

IMIS-DM Redesign/Enhancement

The IMIS-DM and its predecessor, MDAS, have evolved over the years. The software has been modified and new features added as requirements were identified and new procedures developed. As a result, the IMIS-DM code is not as efficient as it should be. Therefore, the IMIS-DM and the supporting software are being completely redesigned and recoded to increase their efficiency, add new capabilities, and provide increased flexibility. The software is being written in an object-oriented programming language to provide for easier growth.

Small PMA

Work is in progress to develop a PMA which is much smaller than the PCMAS II unit used for the IMIS-DD project. The new PMA will be approximately half the size and weight of the PCMAS II, will provide increased internal memory, and use a larger capacity memory cartridge.

Content Data Model

Evaluations of the APS indicated that it provided an effective tool for demonstrating the use of a neutral data base to create and display automated technical data. However, a number of limitations and weaknesses were identified which required resolution. The Content Data Model (CDM) effort was established to address these problems.

The CDM effort involved a comprehensive analysis of the contents and requirements for all types of technical data required to maintain Air Force systems. The required data elements were identified, as well as the attributes required to describe them; and the interrelationships between them were specified. The CDM represents data in a neutral format. The individual elements within the CDM are uniquely identified and can be retrieved and manipulated individually. Shared elements within the data base are represented only once, eliminating redundancy.

The CDM is being developed in an iterative process. Initial specifications have been developed and tested. These specifications are being updated to incorporate the results of the tests and to expand the model to ensure that it can effectively represent the requirements of technical data used by other DOD agencies. Progress on the development of the CDM is described in Earl et al., 1990.

Authoring and Presentation System Revision

The authoring and presentation system is being revised to overcome problems identified in this and previous efforts. The system is being designed to make it easier for authors to create data and to make the data compatible with neutral data stored in the CDM format which is being developed for use with the IMIS. This software is also being developed in an object-oriented language.

Improved User Interface

Work is in progress to develop an improved user interface for the IMIS. Work is focusing upon developing an interface for the smaller PMA and techniques to help the technician easily locate and use the information provided by the PMA.

F/A-18 Diagnostic Demonstration

Preparations are being made to conduct a demonstration and evaluation of the IMIS-DM using the F/A-18 aircraft. The F/A-18 Diagnostics Demonstration will provide a much more extensive test of the IMIS diagnostic technology. It will include a controlled evaluation where performance of technicians using the PMA/IMIS-DM to isolate faults in an F/A-18 subsystem will be compared with performance of technicians using paper technical manuals to troubleshoot the subsystem. In addition, it will include an unconstrained field test where technicians will use the PMA and the IMIS-DM in day-to-day operations to troubleshoot "real" problems in the subsystem as they are encountered. The demonstration will use the redesigned IMIS-DM, the small PMA, and the improved user interface. The data will be developed using the redesigned authoring and presentation systems. The F/A-18 demonstration is currently scheduled for the fall of 1990.

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ACRONYMS

A/C	- Aircraft
AFHRL	- Air Force Human Resources Laboratory
AFS	- Air Force Specialty
AFSC	- Air Force Specialty Code
AGS	- Aircraft Generation Squadron
AIP	- Aircraft Interface Panel
AMU	- Aircraft Maintenance Unit
APS	- Authoring and Presentation System
BIT	- Built-in Test
CAMS	- Core Automated Maintenance System
CDM	- Content Data Model
CMAS	- Computer-based Maintenance Aid System
CMOS	- Complementary Metal Oxide Semiconductor
DSP	- Digital Signal Processor
DTU	- Data Transfer Unit
FCC	- Fire Control Computer
FCR	- Fire Control Radar
FI	- Fault Isolation Manual
FOD	- Foreign Object Damage
FOM	- Facilitate Other Maintenance
GDE	- General Dynamics, Electronics Division
GDFW	- General Dynamics Fort Worth
IFF	- Identify Friend or Foe
IMIS	- Integrated Maintenance Information System
IMIS-DD	- IMIS Diagnostics Demonstration
IMIS-DM	- IMIS Diagnostic Module
JG	- Job Guide
LCD	- Liquid Crystal Display
LPRF	- Low Power Radio Frequency Unit
LRU	- Line Replaceable Unit
MDAS	- Maintenance Diagnostic Aiding System
MFL	- Maintenance Fault List
MIW	- Maintenance Information Workstation
MTBF	- Mean Time Between Failure
OCU	- Operational Capability Upgrade
PCMAS	- Portable Computer-based Maintenance Aid System
PMA	- Portable Maintenance Aid
R&D	- Research and Development
R&R	- Remove and Replace
RDR	- Radar
SEI	- Systems Exploration, Inc.
SRL	- Systems Research Laboratories
SSC	- Side Stick Controller
TAC	- Tactical Air Command
TFW	- Tactical Fighter Wing
TO	- Technical Order
WD	- Wiring Diagram
XMTR	- Transmitter

APPENDIX A
IMIS-DD FAULT INSERTION LIST

FAULT 01

TITLE - Failed 56-MHz Clock input to Radar Computer.

SYMPTOM EXPECTED - MFL Radar (RDR) 595, "LPRF Clock Detect" (BIT).
MFL RDR 018, "LPRF Clock Detect" (NAM).

ACCESS - Door 1202.

CAUTION - None.

PROCEDURE - Power-Down Radar, Open door, Remove cable, Close door, Power-On.

1.1 Shut off Radar Power by switching the Radar Panel Mode control switch to "OFF."¹

1.2 Open ACCESS Door 1202.

1.3 Remove 56-MHz cable J4 from Fire Control Radar Computer.

1.4 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." This will cause the Radar to perform the BIT test and collect the MFL on the DTU cartridge.

1.5 Close and secure door.

1.6 Perform PCMAS fault isolation using the MFL collected on the DTU cartridge.

FAULT 02

TITLE - Failed 56-MHz Clock input to DSP in BIT.

SYMPTOM EXPECTED - MFL RDR 400 "DSP Bus External WAT."

ACCESS - Door 1202.

CAUTION - None.

PROCEDURE - Shut Radar off, Open door, Remove cable, Close door, Power-On Radar.

2.1 Shut off Radar Power by switching the Radar Panel Mode control switch to "OFF."

2.2 Open Door 1202.

¹Items in quotation marks are identified as they appear on the aircraft.
Fault code definitions are provided in the 94FI.

2.3 Remove 56-MHz cable J4 from Digital Signal Processor.

2.4 Close and secure door.

2.5 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." This will cause the Radar to perform the BIT test and collect the MFL on the DTU cartridge. Wait for the BIT test to complete before proceeding.

2.6 Perform PCMAS fault isolation using the MFL collected on the DTU cartridge.

FAULT 03

TITLE - Hardline failed between Transmitter (XMTR) and LPRF in BIT mode.

SYMPTOM EXPECTED - MFL RDR 319 "Xmtr Calibration."

ACCESS - Door 1202.

CAUTION - None.

PROCEDURE - Shut Radar Off, Open door, Remove hardline, Close Door, Turn Radar On.

3.1 Shut off Radar Power by switching the Radar Panel Mode control switch to "OFF."

3.2 Open ACCESS Door 1202.

3.3 Remove XMTR to LPRF hardline cable 2J7 using 9/16" open-end wrench.

3.4 Close and secure door.

3.5 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." This will cause the Radar to perform the BIT test and collect the MFL on the DTU cartridge.

3.6 Perform PCMAS fault isolation using the MFL collected on the DTU cartridge.

FAULT 04

TITLE - Potentiometer Failure in Throttle Grip Found during BIT.

SYMPTOM EXPECTED - MFL RDR 572 "A/D Circuits" (BIT).
MFL RDR 017 "A/D Circuits" (NAM).

ACCESS - Cockpit.

CAUTION - None.

PROCEDURE - Shut Radar Off, Remove Cable.

4.1 Shut off Radar Power by switching the Radar Panel Mode control switch to "OFF."

4.2 Disconnect the Throttle Grip cable connector. Note: This will require removal of the Identify Friend or Foe (IFF) Control Box to FOM.

4.3 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." This will cause the Radar to perform the BIT and collect the MFL on the DTU cartridge.

4.4 Perform PCMAS fault isolation using the MFL collected on the DTU cartridge.

FAULT 05

TITLE - No control of antenna elevation from forward cockpit (B model).

SYMPTOM EXPECTED - Antenna does not move to elevation position commanded by ANT ELEV switch on forward throttle grip but is OK when commanded by ANT ELEV switch on aft throttle grip.

ACCESS - Cockpit.

CAUTION - Will require approximately 2 hours to insert fault. High probability of Foreign Object Damage (FOD) in cockpit.

PROCEDURE - Turn A/C off, remove T-Grip, install faulty T-Grip, turn A/C on, perform BIT test, perform Ops. Check, R&R faulty T-Grip, perform T-Grip Ops. Check.

5.1 Power-off the A/C and remove cooling air. Secure A/C by performing Aircraft Safe for Maintenance (JG10-30-01).

5.2 Remove the T-Grip assembly and install a faulty T-Grip with an open Ant. Elev. Switch.

5.3 Power-up A/C and apply cooling air.

5.4 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." At completion of RDR BIT, no additional MFLs should have occurred.

5.5 Perform Throttle Grip Operational Checkout per 94JG-60-1, paragraph 3-14. Failure should be noted directing fault isolation at 94-61-EN.

5.6 Perform PCMAS fault isolation using operator-observed failure EN. PCMAS should direct Remove and Replace (R&R) of the Throttle-Grip (T-Grip).

FAULT 06

TITLE - No control of antenna elevation (B model).

SYMPTOM EXPECTED - Antenna does not move to elevation position commanded by ANT ELEV switch on forward throttle grip but is OK when commanded by ANT ELEV switch on aft throttle grip.

ACCESS - Crew compartment matrix assembly.

CAUTION - None.

PROCEDURE - Turn A/C off, remove relay 9473K5, install faulty relay, turn A/C on, perform BIT test, perform Ops. check, R&R faulty relay, perform T-Grip Ops. Check.

- 6.1 Power-off the A/C and remove cooling air. Secure A/C by performing Aircraft Safe for Maintenance (JG10-30-01).
- 6.2 Remove relay 9473K5 and install a faulty relay with pins cut to cause the relay to be open between B2 & B3, C2 & C3, D2 & D3, in the not-energized position.
- 6.3 Power-up A/C and apply cooling air.
- 6.4 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." At completion of RDR BIT, no additional MFLs should have occurred.
- 6.5 Perform Throttle Grip Operational Checkout per 94JG-60-1, paragraph 3-14. A failure should be noted directing fault isolation to 94-61-EN.
- 6.6 Perform PCMAS fault isolation using operator-observed failure EN. PCMAS should direct R&R relay.

FAULT 07

TITLE - No control of antenna elevation (B model).

SYMPTOM EXPECTED - Antenna does not move to elevation position commanded by ANT ELEV switch on either forward or aft throttle grip.

ACCESS - Crew compartment matrix assembly.

CAUTION - None.

PROCEDURE - Turn A/C off, remove relay 9473K5, install faulty relay, turn A/C on, perform BIT test, perform Ops. Check, R&R faulty relay, perform T-Grip Ops. Check.

- 7.1 Power-off the A/C and remove cooling air. Secure A/C by performing Aircraft Safe for Maintenance (JG10-30-01).
- 7.2 Remove relay 9473K5 and install a faulty relay with pins B2, C2, and D2 cut.
- 7.3 Power-up A/C and apply cooling air.
- 7.4 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." At completion of RDR BIT, no additional MFLs should have occurred.
- 7.5 Perform Throttle Grip Operational Checkout per 94JG-60-1, paragraph 3-14. Failure should be noted directing fault isolation at 94-61-EQ.
- 7.6 Perform PCMAS fault isolation using operator-observed failure EN. PCMAS should direct R&R relay.

FAULT 08

TITLE - FCR Control Transfer to Aft Failure Side Stick Controller (SSC) Fault (B model).

SYMPTOM EXPECTED - On transfer to aft cockpit, the Target Designator Box still follows front cockpit RDR CURSOR control.

ACCESS - Cockpit.

CAUTION - None.

PROCEDURE - Turn A/C off, install faulty Side Stick Controller (SSC) in forward cockpit, turn A/C on, perform BIT test, perform SSC Ops. Check, R&R faulty SSC, perform SSC Ops. Check.

8.1 Power-off the A/C and remove cooling air. Secure A/C by performing Aircraft Safe for Maintenance (JG10-30-01).

8.2 Remove the SSC assembly and install an SSC with a faulty DESIG RET SRCH switch.

8.3 Power-up A/C and apply cooling air.

8.4 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." At completion of RDR BIT, no additional MFLs should have occurred.

8.5 Perform Side Stick Controller Operational Checkout per 94JG-10-02, paragraph 2-2. Failure should be noted directing fault isolation at 94-61-DZ.

8.6 Perform PCMAS fault isolation using operator-observed failure DZ. PCMAS should direct R&R of forward SSC.

FAULT 09

TITLE - FCR Control Transfer to Aft Failure Relay Failure (B model).

SYMPTOM EXPECTED - On transfer to aft cockpit, the Target Designator Box still follows front cockpit RDR CURSOR control.

ACCESS - Crew Compartment Matrix Assy 5.

CAUTION - None.

PROCEDURE - Turn A/C off, install faulty relay, turn A/C on, perform BIT test, perform SSC Ops. Check, R&R faulty relay, perform SSC Ops. Check.

9.1 Power-off the A/C and remove cooling air. Secure A/C by performing Aircraft Safe for Maintenance (JG10-30-01).

9.2 Remove the relay 9473K6 from the Crew Compartment Matrix Assy 5 and install a faulty relay. Relay fault can be caused by cutting pin Y1 or Y2 on the relay.

9.3 Power-up A/C and apply cooling air.

9.4 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." At completion of RDR BIT, no additional MFLs should have occurred.

9.5 Perform Side Stick Controller Operational Checkout per 94JG-10-02, paragraph 2-2. Failure should be noted directing fault isolation at 94-61-DZ.

9.6 Perform PCMAS fault isolation using operator-observed failure DZ. PCMAS should direct R&R of relay.

FAULT 10

TITLE - FCR Control Transfer to Front Failure Relay Failure (B model).

SYMPTOM EXPECTED - On transfer to front cockpit, the Target Designator Box still follows aft cockpit RDR CURSOR control.

ACCESS - Crew Compartment Matrix Assy 5.

CAUTION - None.

PROCEDURE - Turn A/C off, install faulty relay, turn A/C on, perform BIT test, perform SSC Ops. Check, R&R faulty relay, perform SSC Ops. Check.

10.1 Power-off the A/C and remove cooling air. Secure A/C by performing Aircraft Safe for Maintenance (JG10-30-01).

10.2 Remove the relay 9473K6 from the Crew Compartment Matrix Assy 5 and install a faulty relay. Relay fault can be caused by cutting pin X1 or X2 on the relay.

10.3 Power-up A/C and apply cooling air.

10.4 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." At completion of RDR BIT, no additional MFLs should have occurred.

10.5 Perform Side Stick Controller Operational Checkout per 94JG-10-02, paragraph 2-2. Failure should be noted directing fault isolation at 94-61-ED.

10.6 Perform PCMAS fault isolation using operator-observed failure ED. PCMAS should direct R&R of relay.

FAULT 11

TITLE - Pressure Leak In Waveguide.

SYMPTOM EXPECTED - None.

ACCESS - Door 1202.

CAUTION - None.

PROCEDURE - Power-down A/C, Open door, Loosen Valve, Close door, Power-on A/C.

11.1 Power-off the A/C and remove cooling air. Secure A/C by performing Aircraft Safe for Maintenance (JG10-30-01).

11.2 Open ACCESS Door 1202.

11.3 Loosen Schrader Valve on LPRF to simulate faulty waveguide.

11.4 Power-on A/C and apply cooling air.

11.5 Close and secure door.

11.6 Perform PCMAS fault isolation using RDR 033 as if pilot-observed failure. PCMAS should direct isolation per 94-61 AH sequence and cause operator to R&R waveguide.

FAULT 12

TITLE - Transmitter protect computer count.

SYMPTOM EXPECTED - MFL 340.

ACCESS - Door 3308.

CAUTION - None.

PROCEDURE - Power-down A/C, Open door, install faulty relay, turn A/C on, perform BIT, R&R faulty relay, perform BIT test.

12.1 Power-off the A/C and remove cooling air.

12.2 Remove relay 9473K1 from AC/DC Power Panel 1 (Door 3308) and install faulty relay. Relay fault can be caused by cutting pin X1 or X2 on the relay.

12.3 Power-up A/C and apply cooling air.

12.4 Power-on Radar by switching the Radar Panel Mode Control switch to "AIR." At completion of RDR BIT, MFL 340 should be present.

12.5 Perform PCMAS fault isolation to locate faulty relay.

APPENDIX B
USER EVALUATION QUESTIONNAIRE

The prototype portable maintenance aid you used to perform the F-16 test is an example of how technical data may be delivered in the future. Since you and other technicians will be the users of such a device, your feedback is essential to the development of such a system.

Evaluate the questionnaire items using the 5-point scale appearing to the right of the items. Rate each item by placing an "X" in the appropriate column. Respond to as many of the items as possible but recognize that there may be some items you cannot evaluate based on your limited experience with the maintenance aid. In those cases, place an "X" in the column headed "Can't Evaluate."

A. BACKGROUND INFORMATION

Please fill in the following information:

NAME: _____

Age: _____ Sex: _____ AFS: _____

Job Title _____

How long have you been in the Air Force? _____

How long have you been in maintenance? _____

How much experience do you have with the F-16 Radar system? _____

Have you had any formal training on the F-16 Radar system? _____

B: PHYSICAL FEATURES

ITEM	UNSATISFACTORY	MARGINAL	SATISFACTORY	HIGHLY SATISFACTORY	OUTSTANDING	CAN'T EVALUATE
1. Location of keys						
2. Spacing of keys						
3. Ease of operating keys						
4. Indication (feedback) that key had been pressed						
5. Response time after key press						
6. Adequacy of screen size for displaying information						
7. Spacing of information on screen (was screen too cluttered?)						
8. Brightness of display						
9. Glare on display						
10. Legibility of displayed letters and words (large character size)						
11. Legibility of displayed letters and words (small character size)						
12. Legibility of graphics						
13. Adequacy of detail on graphics						

65933

C: INFORMATION PRESENTATION

ITEM	UNSATISFACTORY	MARGINAL	SATISFACTORY	HIGHLY SATISFACTORY	OUTSTANDING	CAN'T EVALUATE
14. Adequacy of organization and arrangement of information						
15. Adequacy of options available on menus/function keys						
16. Ease of using menus/function keys						
17. Adequacy of graphics						
18. Adequacy of information for performing task						

65933

D: COMPARATIVE ASSESSMENT WITH PAPER

ITEM	UNSATISFACTORY	MARGINAL	SATISFACTORY	HIGHLY SATISFACTORY	OUTSTANDING	CAN'T EVALUATE
19. Overall time and effort required for performing task						
20. Time and effort required to obtain more detail						
21. Extent to which it represents an improvement in displaying maintenance procedures						

65933

E: OPINIONS

22. Are two levels on detail useful? _____

23. Are two levels of detail enough? _____ If not, how many? _____
24. What did you like about the automated system? _____

25. What did you dislike about the automated system? _____

26. If you had a choice, would you use the computer or paper TOs? _____
Why? _____

27. What would you do to improve the automated system? _____

28. Do you foresee any problems in using a computer on the flight-line for maintenance? If so,
what would be required to overcome these problems? _____

TASK DEBRIEFING

Because the observer's notes tended to cover the nature of most of the problems encountered by the subjects, each debriefing session focused on the subject's general likes and dislikes of the preceding task's performance.

The following items were derived from debriefing responses by the subjects in the "Bad Things" category:

1. There are some missing steps to "power-down" the aircraft following BIT. There should be a linked procedure to tell the technician to do so.
2. The PCMAS device was too bulky to use comfortably in the cockpit.
3. There was a tendency to hit "NEXT" too soon, and then wish you could back up and reread one last bit of information from the previous screen. There are too many places where it's impossible to just back up one screen. More familiarity with PCMAS would help you to use it right, but this problem still needs to be solved.
4. It is hard to understand the screen that comes up immediately after you run BIT, especially if it passes. If it does, the screen should say "no faults" or something like that, instead of just leaving the line blank.
5. Unless PCMAS is very flexible, experienced people will go ahead and do a task, then go back to PCMAS after they're finished, and step through a procedure just to get the information that needs to go into CAMS.
6. PCMAS has the ability to consider wiring problems in its diagnostics, unlike most Fault Isolation manuals. Since a lot of users won't have much experience with wiring problems, PCMAS should present more detailed information and bigger graphics on finding connectors, and on locating pins on connectors.
7. When you're told to repair a cable after a continuity check, you should still be able to see the pin numbers that correspond to the bad wires, in case you forget what they were.

The following items were selected from debriefing responses in the "Good Things" category:

1. PCMAS found a wire problem. We probably would have swapped a box first if we hadn't had PCMAS. I like something that can find wire problems. They're hard to troubleshoot with TOs.
2. The logic that PCMAS uses is good. Swapping the transmitter was logical [in this task], even though the relay would have been easy to swap. The transmitter is what we would have done on our own.
3. You get faults quicker when PCMAS runs BIT instead of the aircraft.
4. When we use the TOs, we don't usually check that breaker first, because the TOs don't tell you to do it.
5. In PCMAS, all the TOs are together, right in the computer.
6. Like the availability of history information. We use it a lot. This is a lot easier than CAMS.

7. If this were connected to CAMS, when you were done with a job you wouldn't have to close the job in CAMS.

8. PCMAS has the potential to track serial-number-controlled items.

Effectivity tracking is a big improvement. The following items were derived from responses to the question, "Do you have any other comments or observations about the use of PCMAS during this particular task?":

1. The demonstration team should have developed a better introduction, making it clear that in its final form, IMIS will not require somebody in the cockpit to run BIT.

2. We just don't use Job Guides on the line for things that we know how to do, like replacing a transmitter or LPRF.

3. PCMAS needs a preview function that lets you look ahead at a procedure without intending to do it. You ought to be able to do this, to prepare for doing a task, before you start it.

4. I'd like to be able to get "MORE" information about only a single step at a time [instead of getting it for a whole task at a time], like hypertext.

EVALUATION QUESTIONNAIRE RESPONSES

The questionnaires were administered to subjects after they had finished all of the problems that were assigned to them. The first 21 items were topics on which the subjects were asked to rate PCMAS, either by itself or in comparison with paper tech orders (See Table 7, Section IV).

The remainder of the questionnaire consisted of open-ended questions with spaces in which the subjects could write their responses. The following paragraphs present questions 22 through 28. The complete written comments of each subject who responded to the question are transcribed exactly as written by the technicians.

(22) Are two levels of detail useful?

1. Yes! Helps the more experienced person to repair the aircraft quicker and yet offers a way for the less experienced to access detailed instructions they might need.

2. Yes, if you don't quite understand exactly what it is the computer wants you to do, it will go into better detail for you.

3. Can't evaluate, did not use that much.

5. The only level used during this procedure was the top level; I found no use to reduce to the other.

6. Yes. When certain procedures are unclear, a more detailed picture helps in finding what is to be worked on.

7. Yes, because experienced personnel may opt not to use the higher detail level, saving manhours. It also gives the less experienced personnel more independence.

9. Yes. For the experienced person, few details; and for the inexperienced, detailed drawings and directions.

10. There should be an expert level with a listing of the procedures and the ability to expound on individual steps, thus enabling the worker to have an overview of the procedures, especially if he or she is extremely qualified.

11. Yes! I think that you should have the option.

12. Yes. Allows for diversity of experience and skill levels.

(23) Are two levels of detail enough? If not, How many?

1. Ten subjects answered YES; one did not respond.

2. Subject number 10 answered "Three: No details; Some details; and All (very comprehensive)."

(24) What did you like about the automated system?

1. Speed for troubleshooting wiring problems, history.

2. Seems it would speed up troubleshooting time on a big job.

3. I preferred seeing the illustration using graphics than to have to keep flipping through the FI or the WD. This way you are only looking at what points you need instead of a mass configuration of components linked together as with the FI.

4. Wiring troubleshooting.

5. I liked the ease with which information was easily attainable. The system was easy to use as far as returning to different screen selections.

6. The ease of making a fix was exceptional. It showed me certain parts that I would not have thought of being bad. Consolidating the TOs and use of the correct effectiveness automatically makes troubleshooting quicker.

7. I can troubleshoot much faster and efficiently.

8. It provided more detailed information than the Fault Isolation manual.

9. Part history, showing some things that the FI does not show. If this system does everything I've been told, ordering parts from the line, seeing how many parts are in supply, ending the job at the line, instead of coming in off the line to do paperwork.

10. I like the fact that I have all the TOs I need; the CAMS work and supply ordering are also facilitated. It enables an inexperienced trooper to perform the work better and easier.

11. Faster! In the expect of supply and smaller class to carry than TOs. [This technician liked the idea of a link to supply. Also, he believed the portable computer would be easier to carry than the current TOs.]

12. The fact that you do not need to skip between different tech orders. The idea of updates of tech data via computer.

(25) What did you dislike about the automated system?

1. Great system! Possibly more flexibility on finding theory and schematics would help.
 2. N/A
 3. I basically have no complaints with the system. I have enjoyed and very much appreciate the opportunity to work with this system. Thanks.
 5. The system could use some work on the graphics, also a change in the software. By this I am referring to the way in which the steps of the task are displayed: Instead of pushing the down arrow to read remaining steps, you should push NEXT to display those steps on the next page.
 6. My only problem with this system is when I paged forward and was unable to back up. The other was the arrows for more text. At times I missed them or failed to notice them.
 7. The computer is too large and fragile.
 8. The size and clarity of the graphics. Also, it offered no information pertaining to wiring diagrams.
 9. There's a lot of stuff (directions) not needed for an experienced person. When told to repair a wire, that's all it said: REPAIR WIRE. It didn't say if there were connections within the aircraft. There could have been 100 yards of wire with 20 connections and all it said was to REPAIR WIRE.
 10. The inability to provide info on wiring, the use of graphics: Each step needs at least the option of seeing "the picture." I didn't like the inability to examine the procedures without actually performing the task.
 11. No preview option.
 12. The fact that you can't skip procedures if you determine it is not required.
- (26) If you had a choice, would you use the computer or paper TOs? Why?
1. Depends. In some cases (red balls) paper TOs would probably be quicker because of the setup time of the computer when you troubleshoot by indications only.
 2. Computer won't blow down the ramp and ease of use. Easier to carry around than a bunch of TOs.
 3. Computer, definitely. It saves the hassle of carrying TOs to the job site, and gives much clearer picture of what steps to do.
 4. Depends on the job how simple or how fast need to do the job like RED BALLS and jobs between flights you may not have time to troubleshoot.
 5. Computer. The computer was much easier to handle and work with.
 6. Computer. The computer helps to make troubleshooting easier. It gives you more probabilities than an FI would. A lot of faults would have to be researched in TOs, whereas the computer gives you the likely faults.

7. Computer. I think it saves time.

8. For the majority of our jobs performed on the flight line, I would prefer to use the paper TOs.

9. Because of the radar system containing a lot of LRUs, I'd use the TOs. If we replaced an LRU and it didn't fix the problem, then the computer would be better because it would tell you the options.

10. At this stage, I would prefer the TO, because I usually only need to look at a couple of steps and would rather avoid trudging through the computer, having to stop after each step to hit "NEXT."

11. Computer. Saves time.

12. Computer.

(27) What would you do to improve the automated system?

1. Possibly a picture of scope (REO) indications would help.

2. Add more theory available through it, because if it does end up replacing the TO, there is a lot of valuable information the maintenance person sometimes needs to find out about a certain mode or something to that function.

3. Keep making the progress you are and I am sure it will be a great piece of work equipment.

5. The system does need some changes, but I feel they are not major. An example would be graphics.

6. I would like to see it smaller as I was told it would be. Possibly the diagrams be made more legible and have the arrows directing more text be more in view.

7. Add more graphics.

8. More attention needs to be given to the graphics of the system.

12. Provide a scan function that allows you to look at different procedures to establish a course of action.

(28) Do you foresee any problems in using a computer on the flight-line for maintenance? If so, what would be required to overcome these problems?

1. No real problems except that the computer has to be made very rugged.

2. No, I'm all for it. It would mean ease of maintenance and save manhours, in turn saving the government money.

3. None whatsoever, not even the fear of sunlight, it appears to work clear as ever in the sun.

5. No.

6. No. I would like to see this computer come out quicker than they expect it to.

7. The computer is much too fragile for flight line use on a regular basis.
9. Problems I see are experienced personnel that see MFLs "know" what's wrong. They might not want to even plug it in until they're finished.
10. Ensure the computer is weatherproof and able to take the shock of being dropped.
11. No.
12. Need to insure unit is shock/weather-proofed to enable it to stand up to use and climatic conditions. Batteries need to be long lasting and resistant to memory build-up.

APPENDIX C

SAMPLE DIAGNOSTIC RUN

The diagnostic process using PCMAS as an aid can best be understood by following a typical scenario from the beginning to the end. When IMIS-DD was demonstrated at Homestead AFB, a careful accounting of the various paths taken through the diagnostic sequence was made and analyzed (see Section 4). This appendix is a composite path for a single symptom that includes many of the possible side trips to review forms, switch between novice and expert levels, and to generally exercise the capabilities of PCMAS.

Each step in the process produces a new screen-full of information which the technician uses to determine his or her course of action. It should be noted that the screens were printed from a Sun workstation; thus, they differ slightly in appearance from the screens displayed on the PMA.

MAINTENANCE DATA COLLECTION RECORD			
Man Number	:	System	: 9461
JCN	: 1284212	Priority	: 2
Work Center	: A7CS	Start Hour	: 0003
A/C ID Number	: 810794	Stop Day	:
Location	: Bay12	Stop Hour	:
Time Spc Req	: 1245	Crew Size	: 2
Crit ID	: N/A	Type Maint	: B
Crit Name	: N/A	When Disc	: D
DISCREPENCY	: RDR-595	Radar inop or degraded	
Press enter to continue.			

Screen 1 - Shows a partially filled-in AFTO Form 349. This form is a simulation of the type of form that will be received directly from the IMIS workstation in a fully implemented system. It is a combination of data that will be originated from the pilot debriefing process and from unloading the Data Transfer Cartridge.

A brief description of each of these fields is provided:

JCN (Job Control Number):. This will be assigned by the workstation and will be unique to each task.

Work Center: Identifies the location of the work to be performed. A7CS was the hangar where the IMIS-DD demonstration took place at Homestead AFB.

A/C ID Number: The tail number of the aircraft with the maintenance need. The tail number is used by the PMA to deliver data designed specifically for that aircraft configuration/version.

Location: Bay 12 of the work center.

Time Spc Req: The time the specialist is required to be at the aircraft.

Crit ID: Criticality Identification.

Crit Name: Criticality Name.

System: Identifies the general system of the aircraft with the failure. This is deduced from the failure code that comes in from the debriefing. 9461 is the Radar subsystem on the F-16.

Priority: Assigned by the maintenance supervisor. This depends on how important it is to get that aircraft back in service.

Start Hour: Contains the time that the maintenance technician actually started this task.

Stop Day: Will be filled-in automatically when the task is complete.

Stop Hour: Automatically filled-in at the completion of the maintenance action.

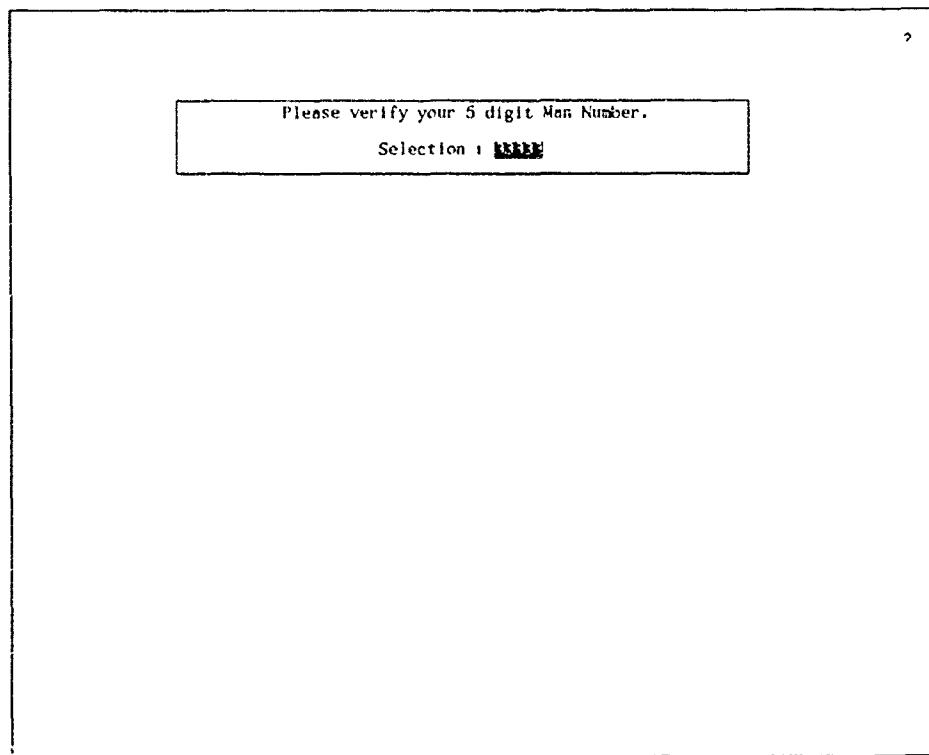
Crew Size: This will be calculated by the IMIS workstation based on the fault and the number of technicians needed to complete the job.

Type Maint: Type of maintenance action. For example, "B" indicates unscheduled maintenance.

When Disc: When the fault was first discovered. For example, "D" indicates during flight with no abort of the mission.

DISCREPANCY: The MFL code and its English language description of the symptom. This provides a starting point for the diagnostic process. The example shows only one MFL present, RDR-595; but several could have been shown and each would contribute to the maintenance decisions made by the diagnostic module.

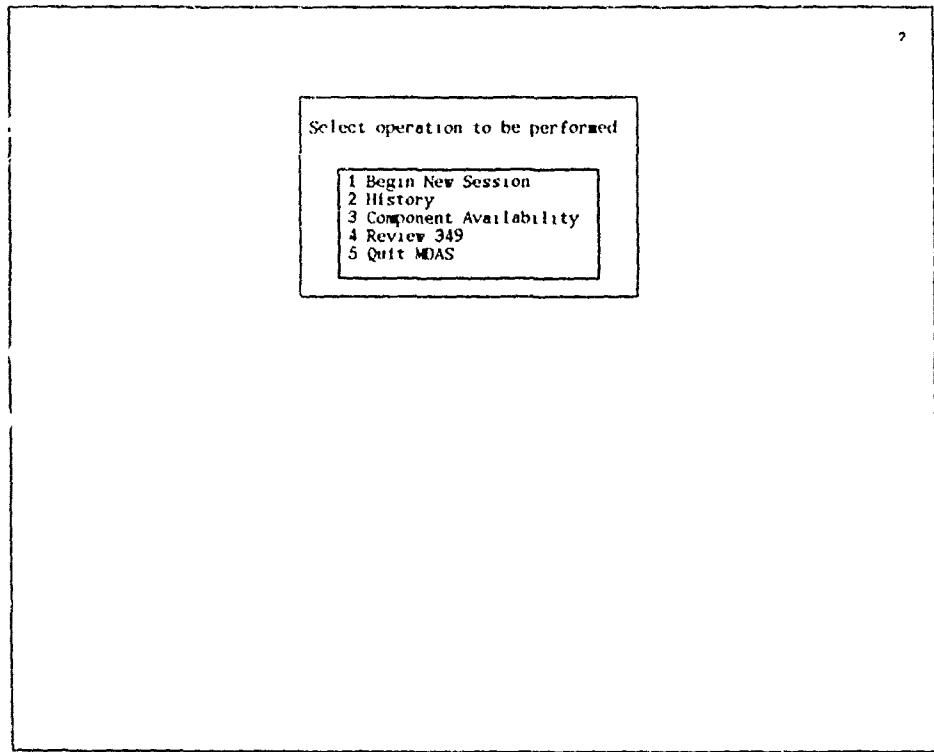
At the completion of the job, the remaining 349 form entries will be automatically filled-in by the PMA.



Screen 2 - The technician enters his or her 5-digit Man Number. In the full IMIS system, this number would be compared with a list of possible and authorized Man Numbers contained in the base personnel computer system. The training level, skill level and security level assigned to that technician would also be compared with the requirements of the task.

INITIAL DATA COLLECTION RECORD					
Man Number	:	33333	System	:	9461
JCN	:	1284212	Priority	:	2
Work Center	:	A7CS	Start Hour	:	0003
A/C ID Number	:	810794	Stop Day	:	
Location	:	Bay12	Stop Hour	:	
Time Spc Req	:	1245	Crew Size	:	2
Crit ID	:	N/A	Type Maint	:	B
Crit Name	:	N/A	When Disc	:	D
DISCREPENCY	:	RDX-595	Radar inop or degraded		
PRESS F10 KEY TO CONTINUE					

Screen 3 - The AFTO Form 349, with the Man Number filled-in, is now ready for use during the diagnostic process.



Screen 4 - The first menu is presented to the technician. The following options are available:

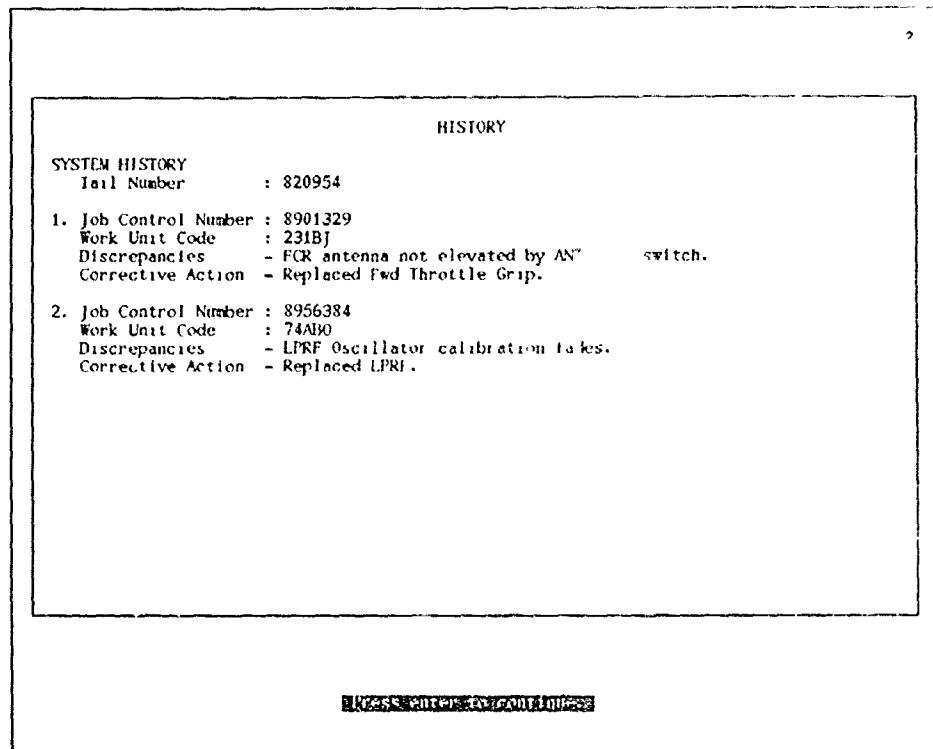
"Begin New Session" - Start the diagnostic procedure. If the technician had interrupted a procedure for some reason, the number 2 option would be to resume the previous session where it was interrupted.

"History" - Present the history of this tail number for review.

"Component Availability" - Shows the number of LRUs available in supply.

"Review 349" - Presents the 349 form.

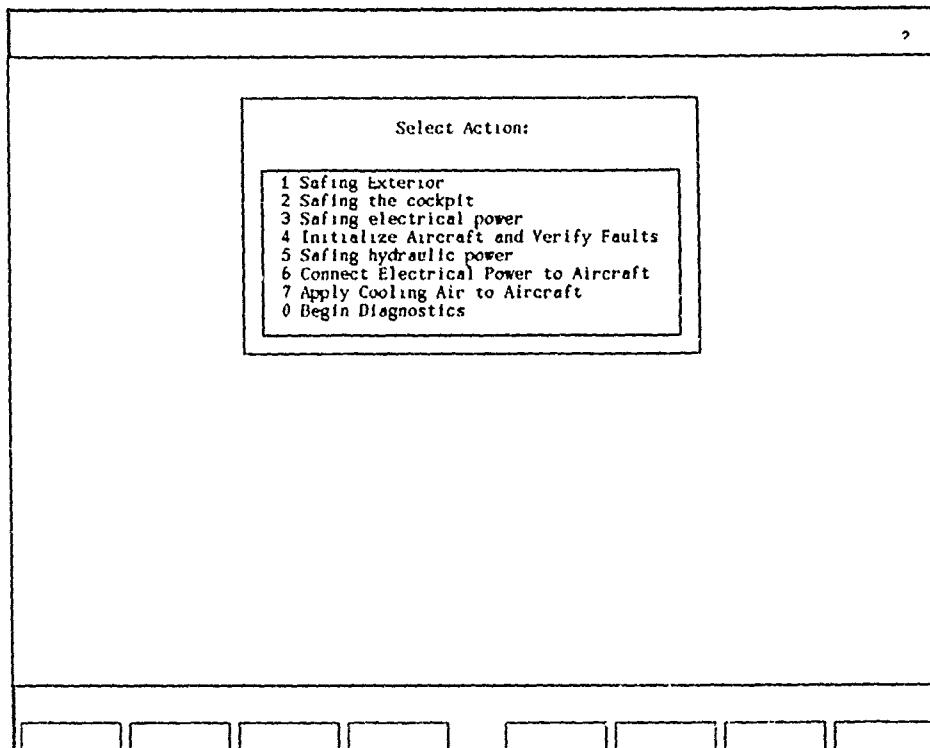
"Quit MDAS" - End the diagnostic session.



Screen 5 - If the technician had selected History, the portable would present the simulated repair history for the specific aircraft in latest-first format. In the full IMIS system, the historical data would come from CAMS. This screen shows the last two operations performed on the aircraft: replacement of the forward throttle grip and replacement of a Low Power Radio Frequency (LPRF) LRU from the Radar subsystem.

AVAILABILITY OF LRU'S	
Description	Number Available
FCR Cable Assembly	2
REO	2
Aft Side Stick Controller	2
Aft Throttle Grip	2
Radar Antenna Assembly	5
Digital Signal Processor	2
Fire Control Computer	2
FCR Computer	2
Forward Side Stick Controller	2
Fwd Throttle Grip	2
Low Power RF Unit	2
Nacelle Eq Bay AC/DC Pwr Panel	5
Radar Control Panel	2
Side Stick Controller	2
Throttle Grip	3
Waveguide Assembly	2
FCR Transmitter	2

Screen 6 - If the technician had selected the Component Availability option, the LRUs in stock for this configuration of aircraft would be shown. This is simulated data showing the type of information that would be retrieved from the CAMS system via the IMIS workstation.



Screen 7 - The initial menu allows the technician to proceed through any of the safing procedures listed, initialize the aircraft and verify the faults (item 7), or start the diagnostic process by selecting "0."

TASK: Initialize Aircraft and Verify Faults							
INPUT CONDITIONS							
Applicability: All							
Required Conditions:							
• Aircraft Safe for Maintenance							
• Power off							
• Panel 2308 open							
Personnel Recommended: One							
Support Equipment: None							
Supplies (Consumables): None							
Other Recommendations: None							
NEXT	BACK	RETRN					

Screen 8 - When the technician selects "7" in the previous screen, the initialization of the aircraft and verification of the fault begins. This screen shows the input conditions to that operation. Pressing "NEXT" allows PCMAS to proceed.

TASK: Open Access Door 2308

INPUT CONDITIONS

Applicability: All

Required Conditions:

- Aircraft safe for maintenance

Personnel Recommended: One

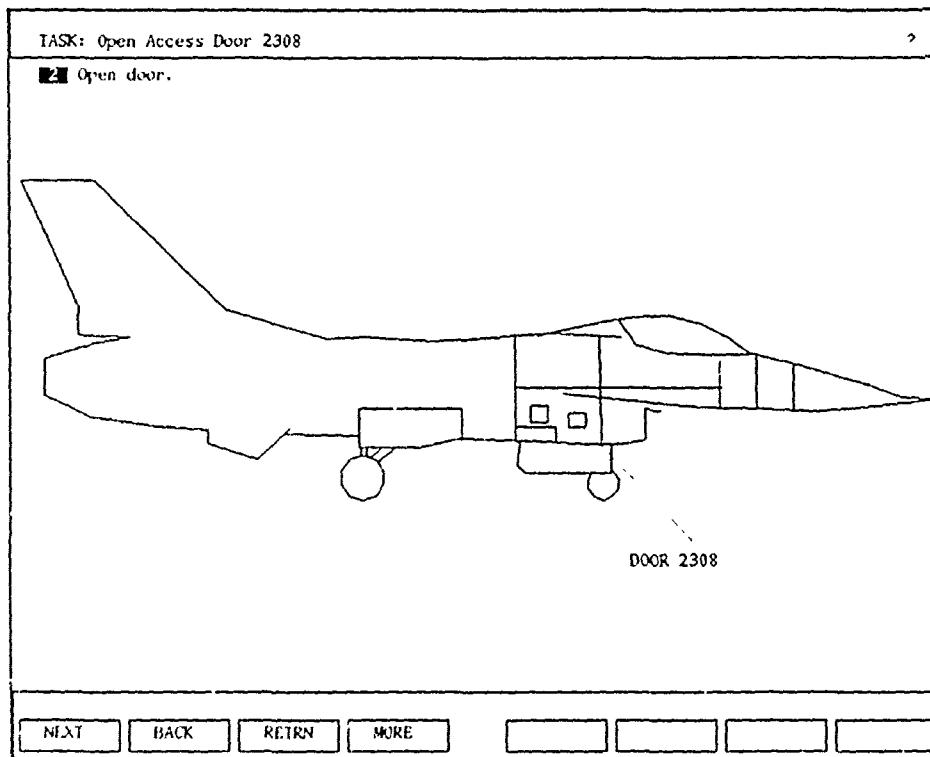
Support Equipment: None

Supplies (Consumables): None

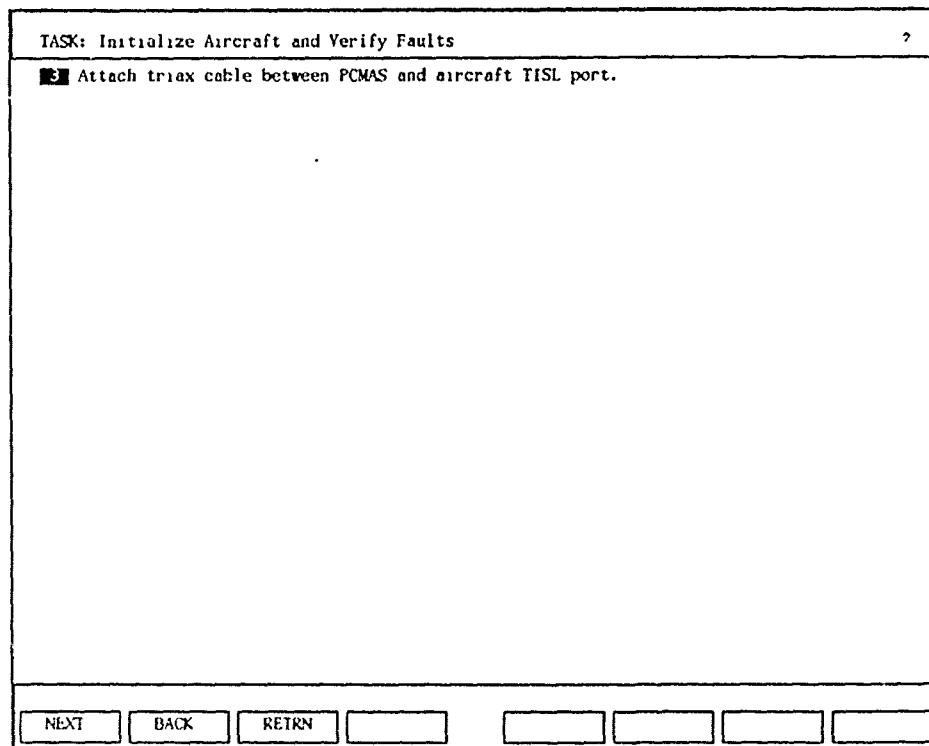
Other Recommendations: None

NEXT BACK RETURN

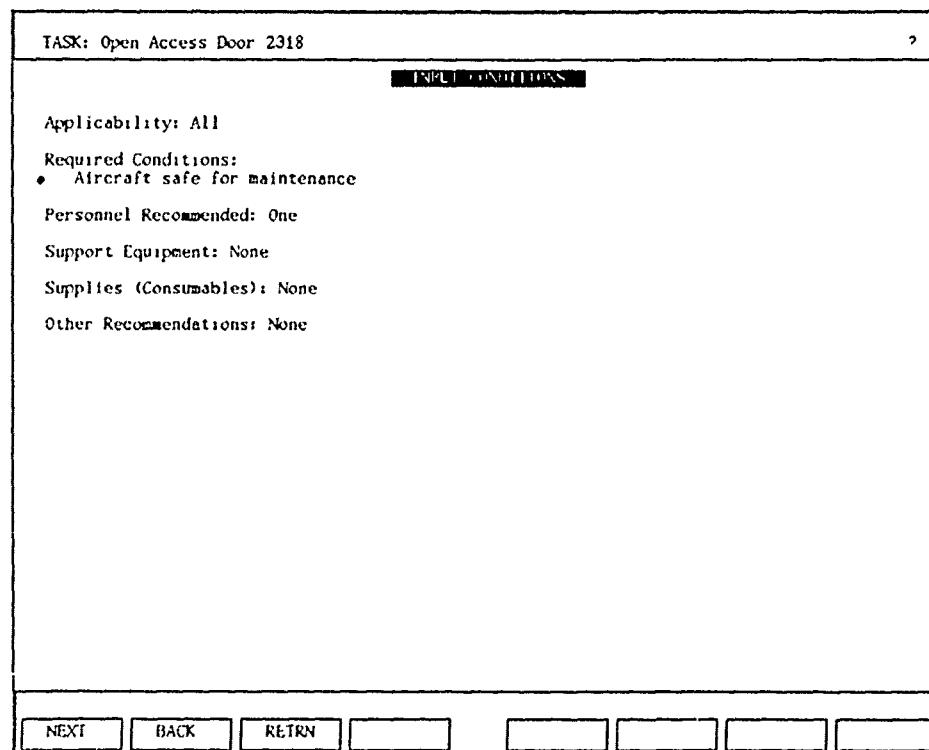
Screen 9 - The first task is to open access door 2308. The input conditions for this task are shown here.



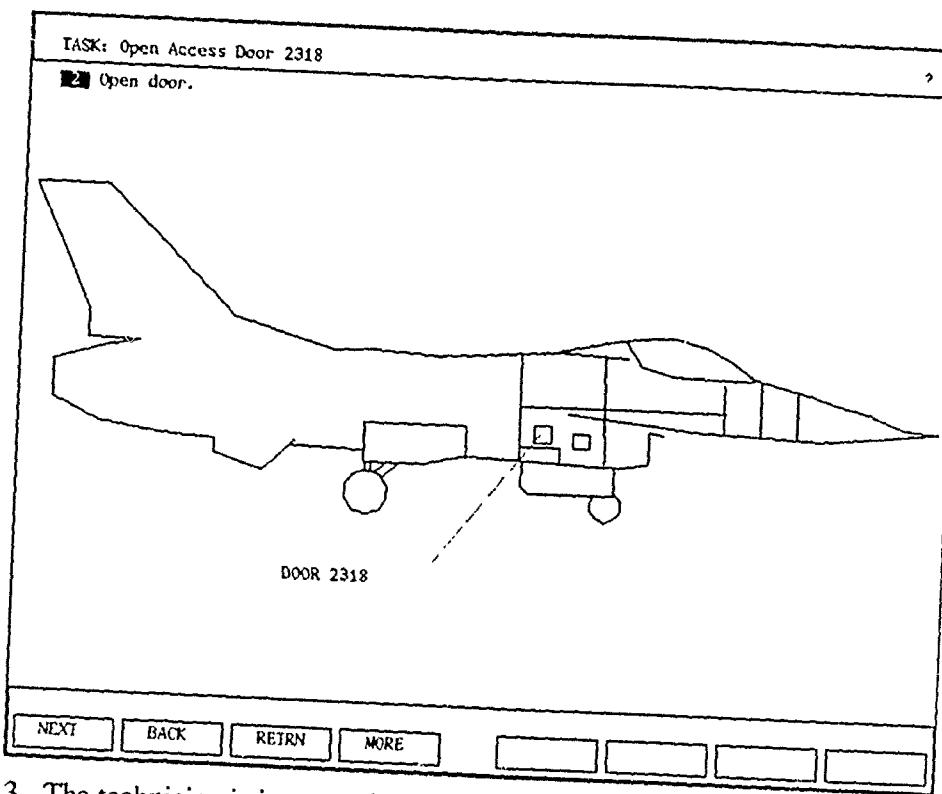
Screen 10 - The expert track for this step shows only the general location of door 2308.



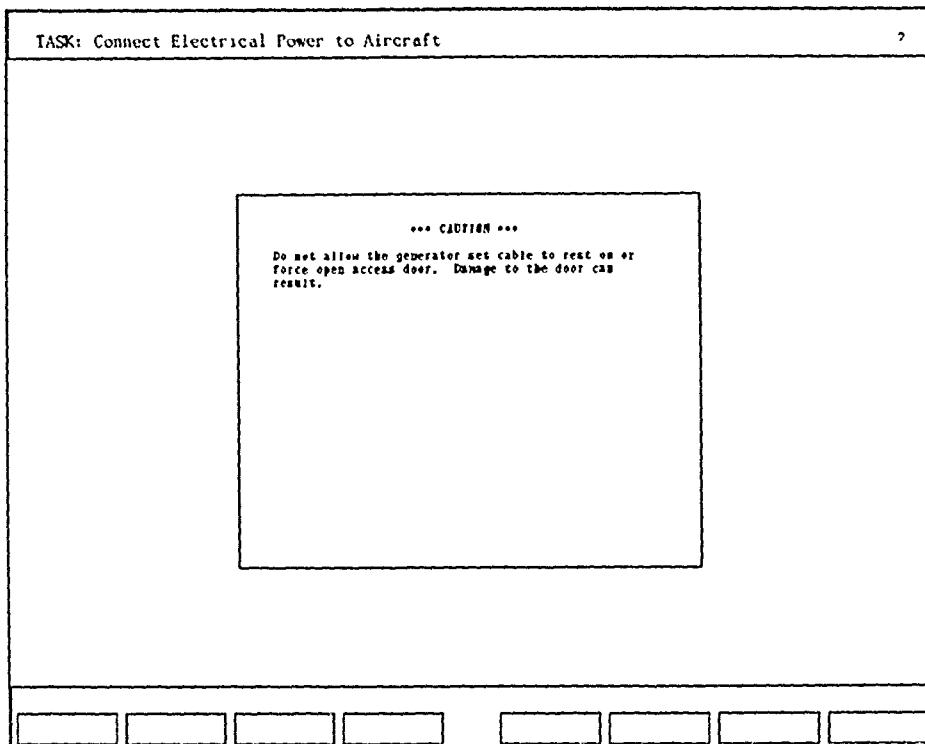
Screen 11 - The technician is instructed to attach PCMAS to the aircraft 1553 bus via the TISL port.



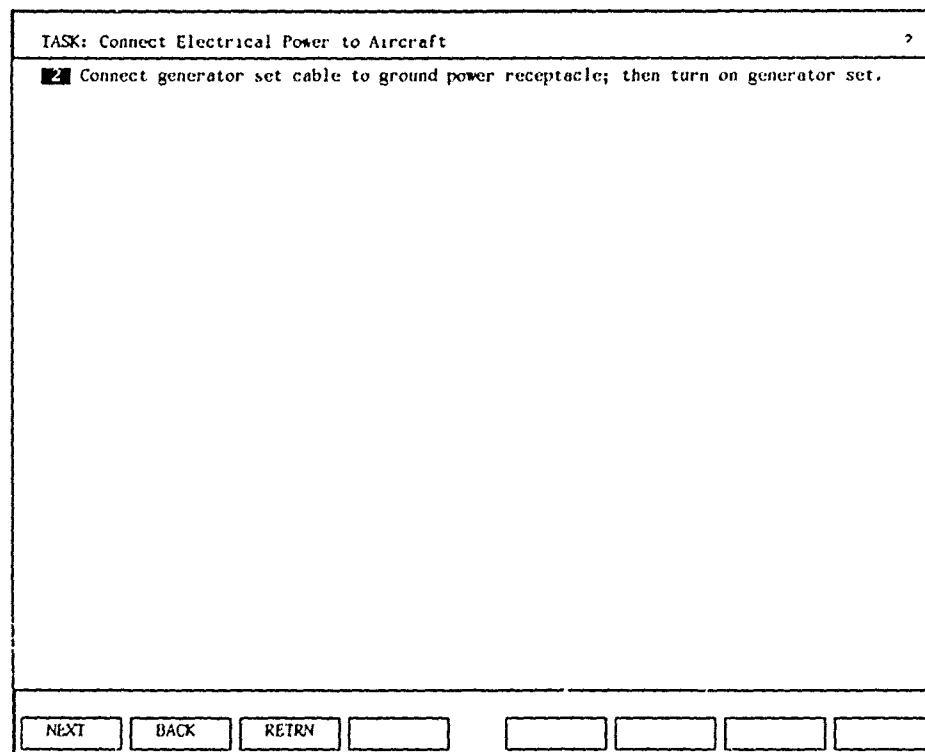
Screen 12 - The input conditions for the next task (Open Access Door 2318).



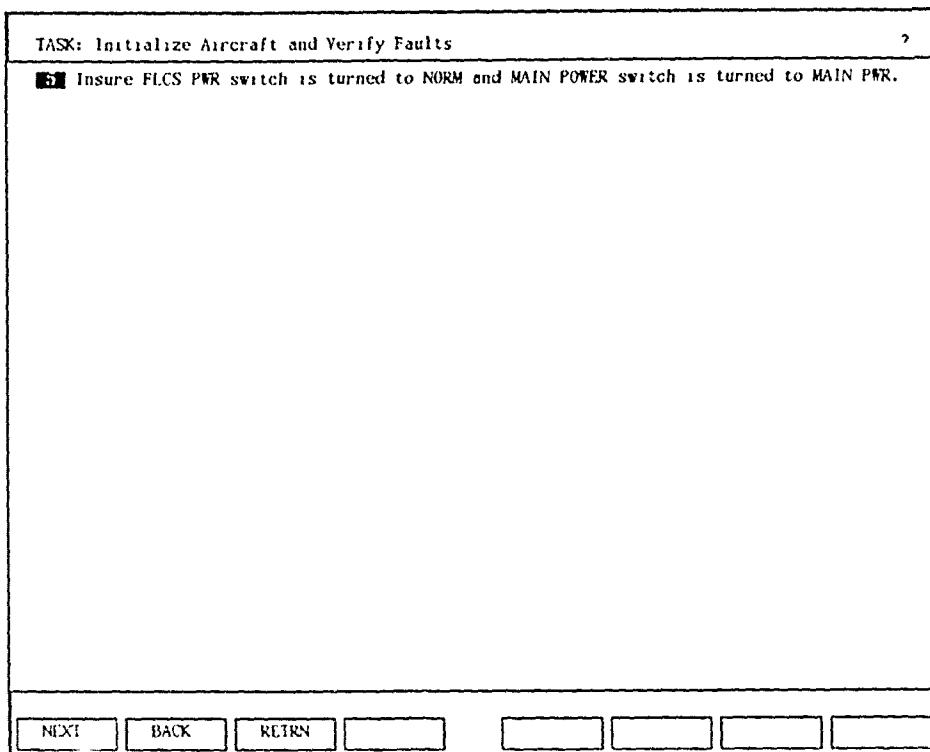
Screen 13 - The technician is instructed to open door 2318 in order to attach the generator set power umbilical.



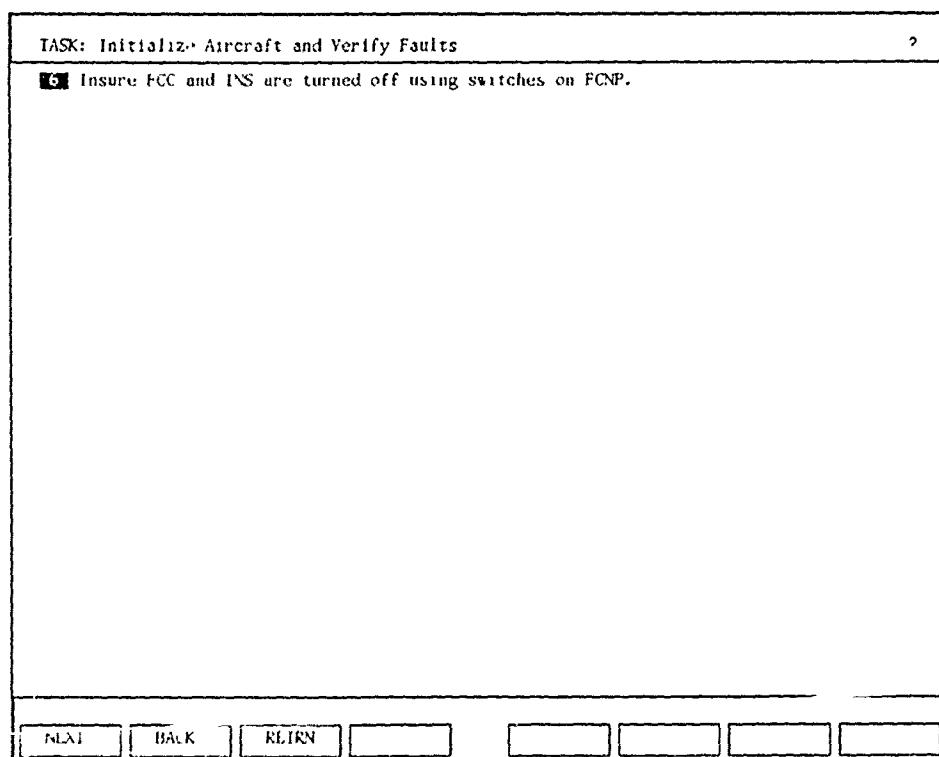
Screen 14 - The technician is cautioned against damaging the door with the generator set cable. To proceed past this point the technician will have to press "ENTER" on the keyboard (not shown on screen) rather than "NEXT".



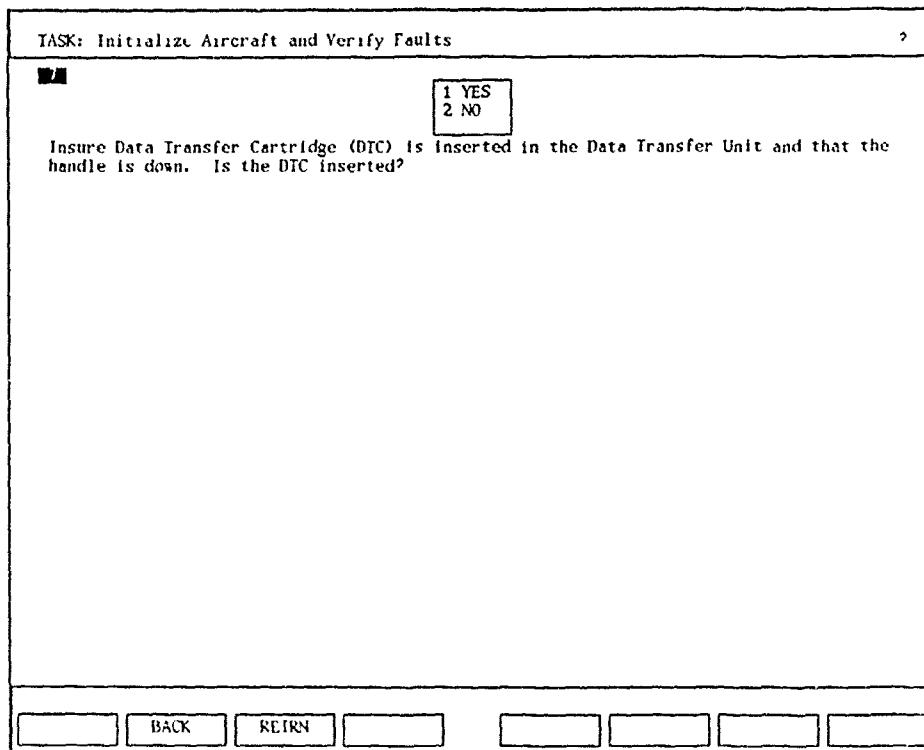
Screen 15 - The technician is directed to connect power to the aircraft and turn the generator on.



Screen 16 - Directions to set cockpit switches for the test.

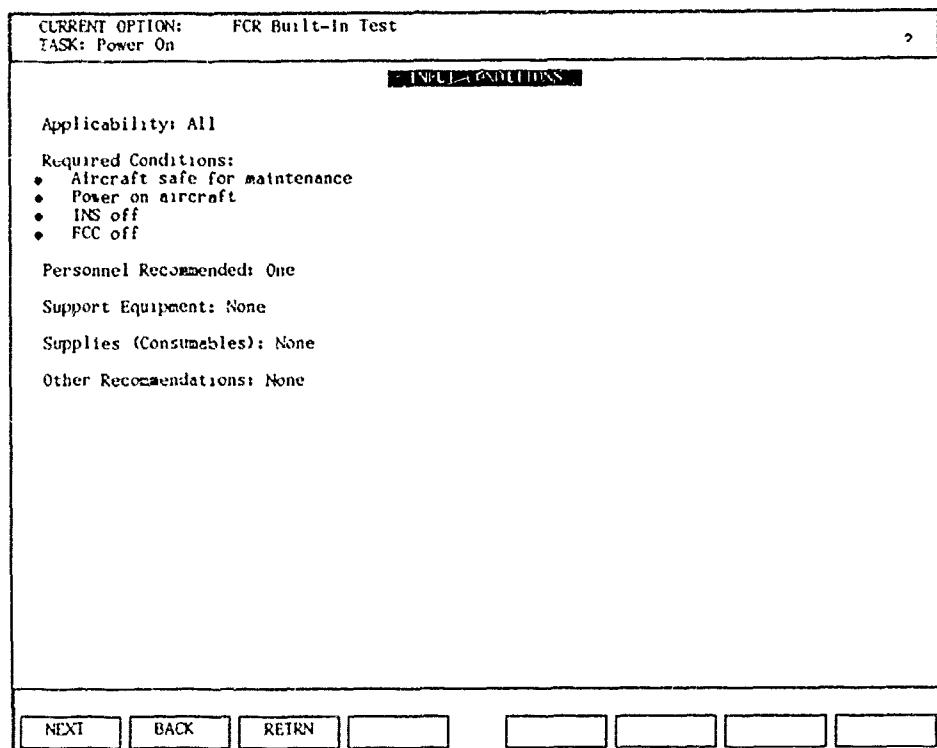


Screen 17 - Directions to shut down the FCC and INS. When power is removed from these two LRUs, PCMAS will be able to take control of the 1553 communications bus.

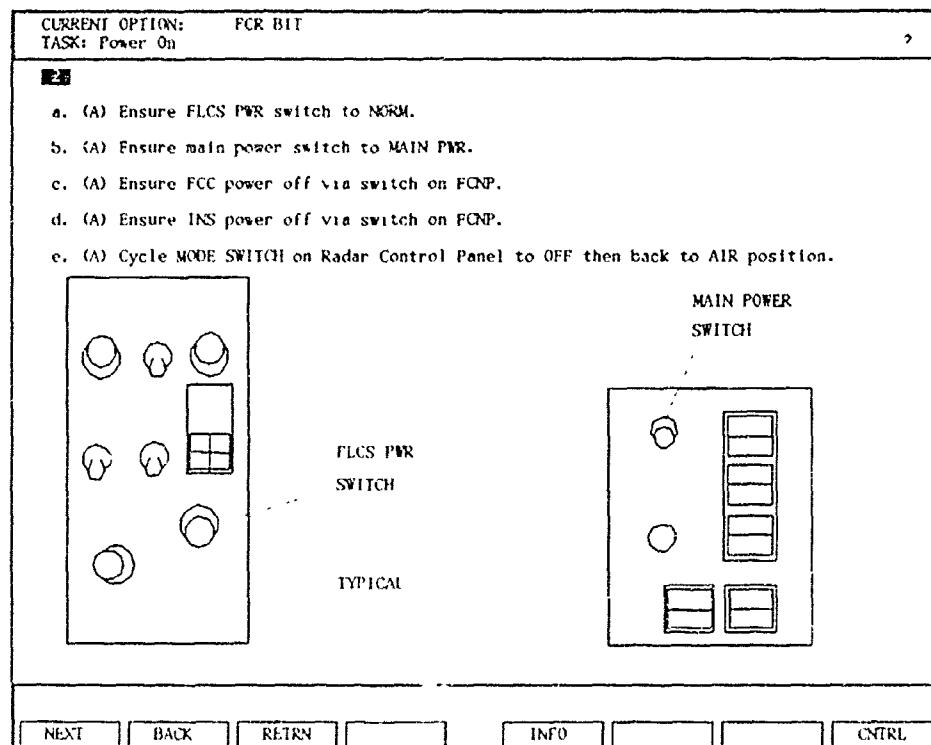


Screen 18 - The Data Transfer Cartridge contains a record of all the faults that the aircraft has experienced during the last flight. This step ensures that the cartridge is installed in the cartridge reader and ready to be read by PCMAS. When the technician answers "YES," PCMAS will unload the fault codes from the cartridge into its own memory to start the diagnostic process.

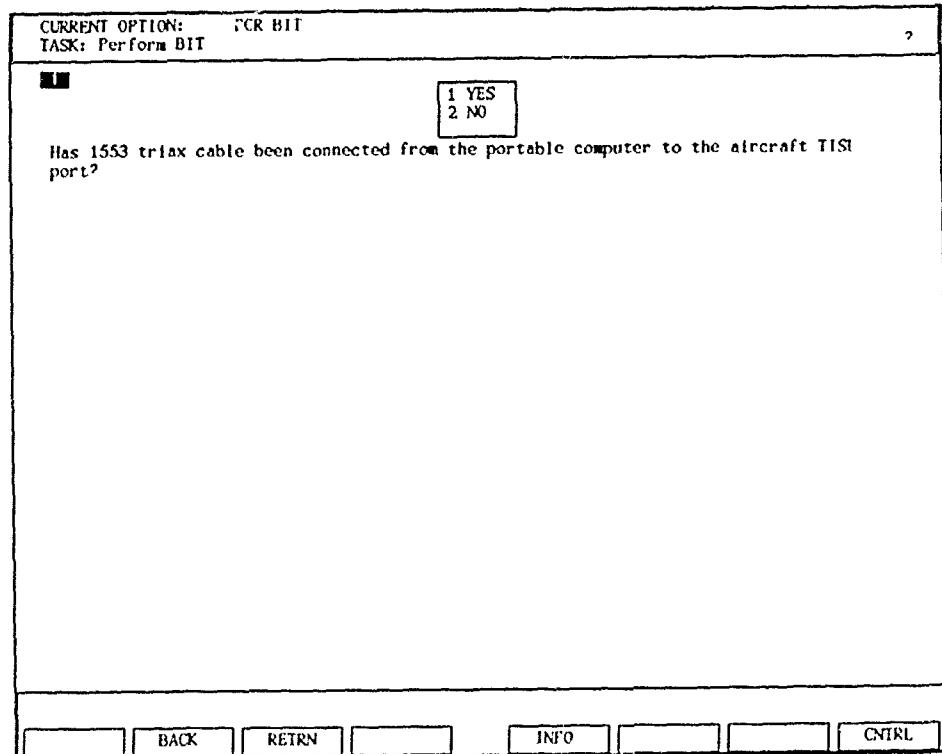
If the technician selects "NO," the operation of reading the cartridge will be bypassed.



Screen 19 - This screen shows the input conditions for running the FCR Built-In Test. It shows that power should be applied to the aircraft and that the INS and FCC should be powered-off to allow PCMAS to control the 1553 bus.



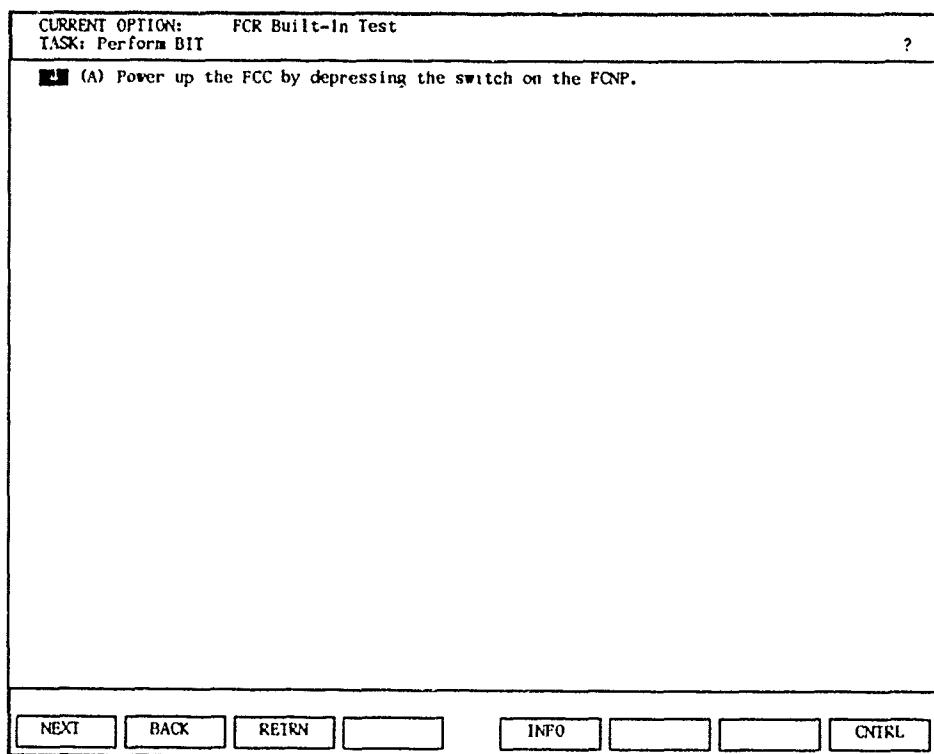
Screen 20 - The complete setup to perform BIT is shown in this screen. Each switch is identified and located in the cockpit for the maintenance technician.



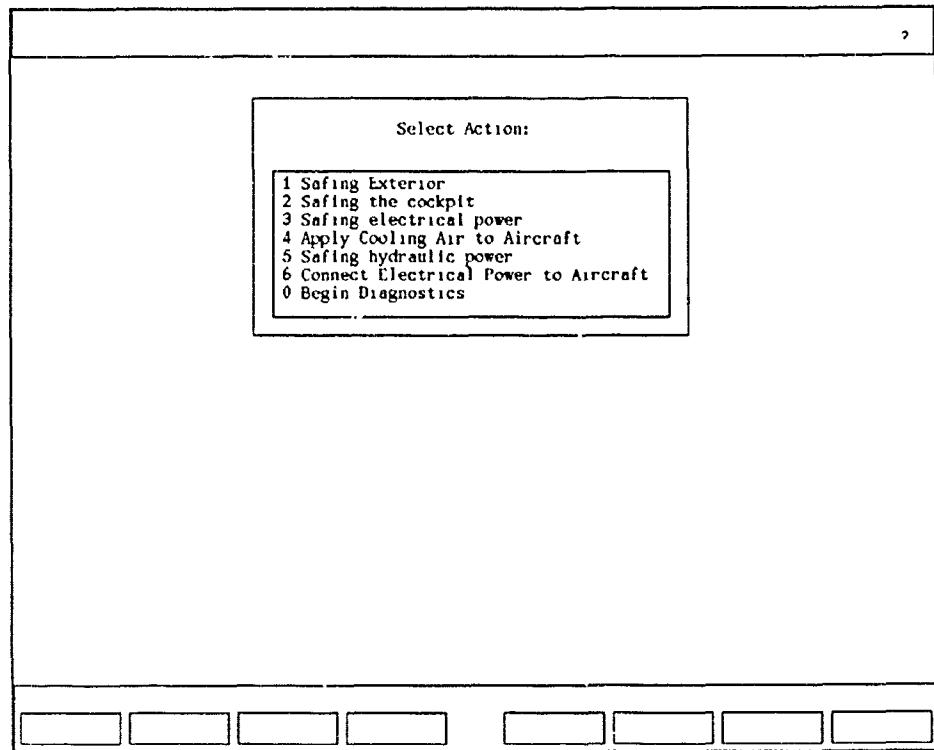
Screen 21 - This question is asked of the maintenance technician as the last step in preparation for BIT execution. If the technician answers that the PMA is connected to the aircraft via the TISL port, the portable will initiate BIT. If the technician answers "NO," then the PMA allows the technician to manually run the BIT and enter the results into the portable computer.

CURRENT OPTION: FCR Built-In Test	?
TASK: Perform BIT	
Symptoms from the Built In Test:	
RDR-595	Radar inop or degraded
Symptoms from the 349:	
RDR-595	Radar inop or degraded
NEXT	

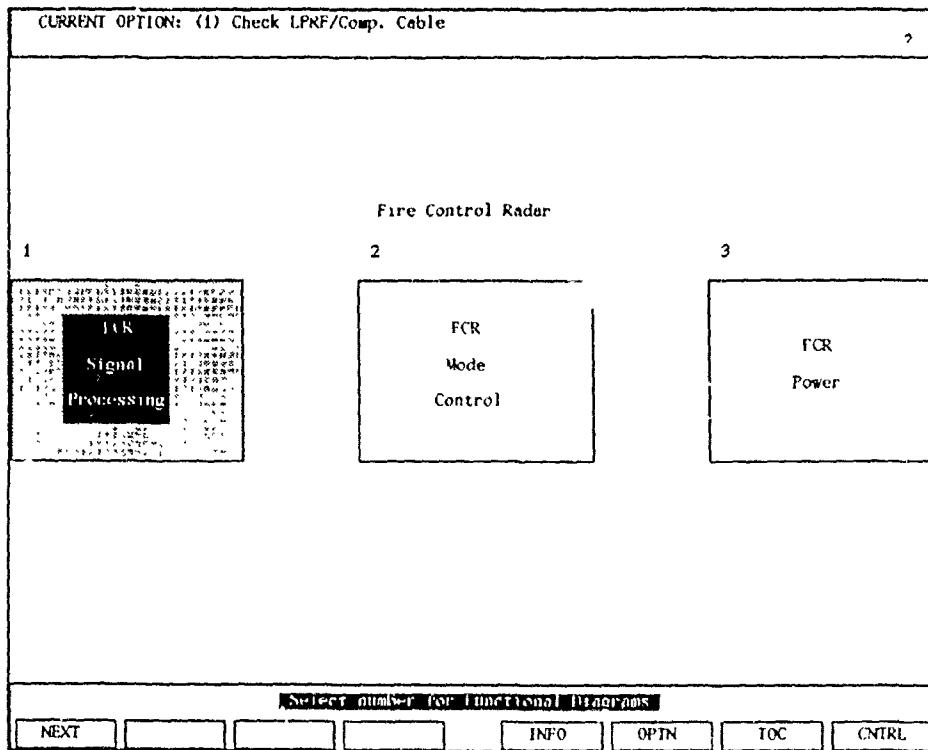
Screen 22 - The results of the BIT test are displayed to the technician in both the MFL code (RDR-595) and the English language interpretation of the code (Radar inop or degraded). The symptom from the 349 form is also displayed to act as a reference point to the beginning of the maintenance session.



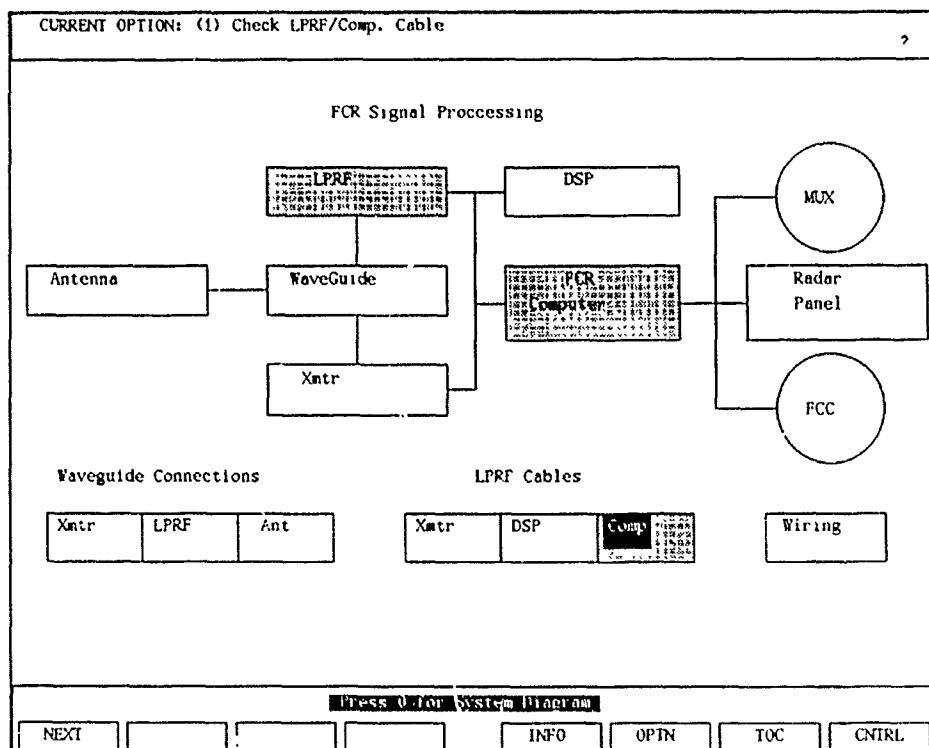
Screen 23 - The technician is being directed to power-up the FCC in order to restore the aircraft to the state it was in before the BIT test was initiated.



Screen 24 - The menu shown in screen 7 is reentered to allow the diagnostic process to continue. Notice that the task just completed, Initialize Aircraft and Verify Faults, has been removed from the menu.

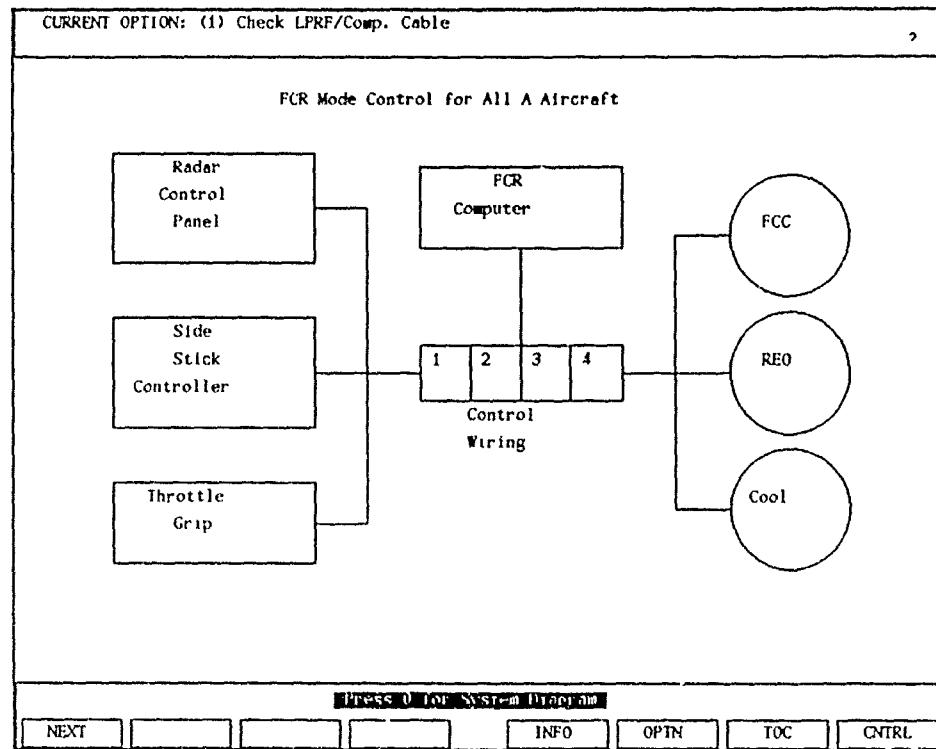


Screen 25 - If the technician selects "0," the first functional diagram is created and displayed for him or her. This diagram indicates that the Current Option (top of screen) is to "Check LPRF/Comp Cables". From the shading of the block diagram, you can see that the operation will be concerned with the FCR Signal Processing portion of the Radar subsystem (black-boxed letters). By pressing 1, 2, or 3, the technician will be presented with a breakdown of the components in the selected area. The selected procedure may be invoked by pressing "NEXT."

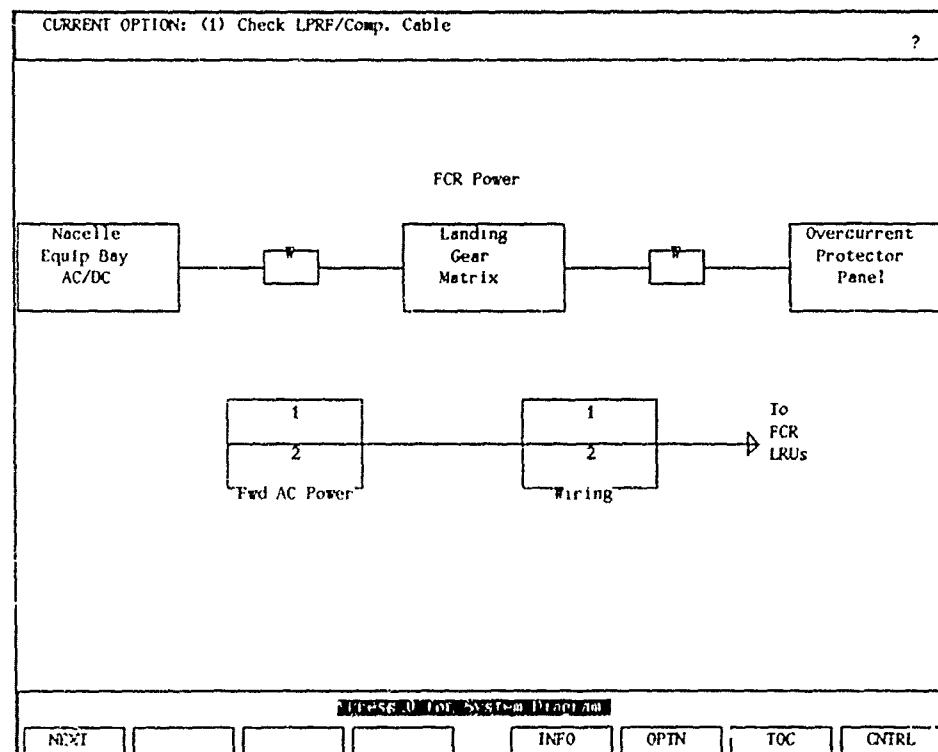


Screen 26 - In this case, the technician wanted to view the block diagram of the signal processing subsystem. This diagram shows the principal LRUs that make up the subsystem (connected with lines), as well as the individual waveguide connections, the LPRF Cables, and the wiring (in isolated boxes). This convention allows an otherwise complex diagram to be shown in a compact manner.

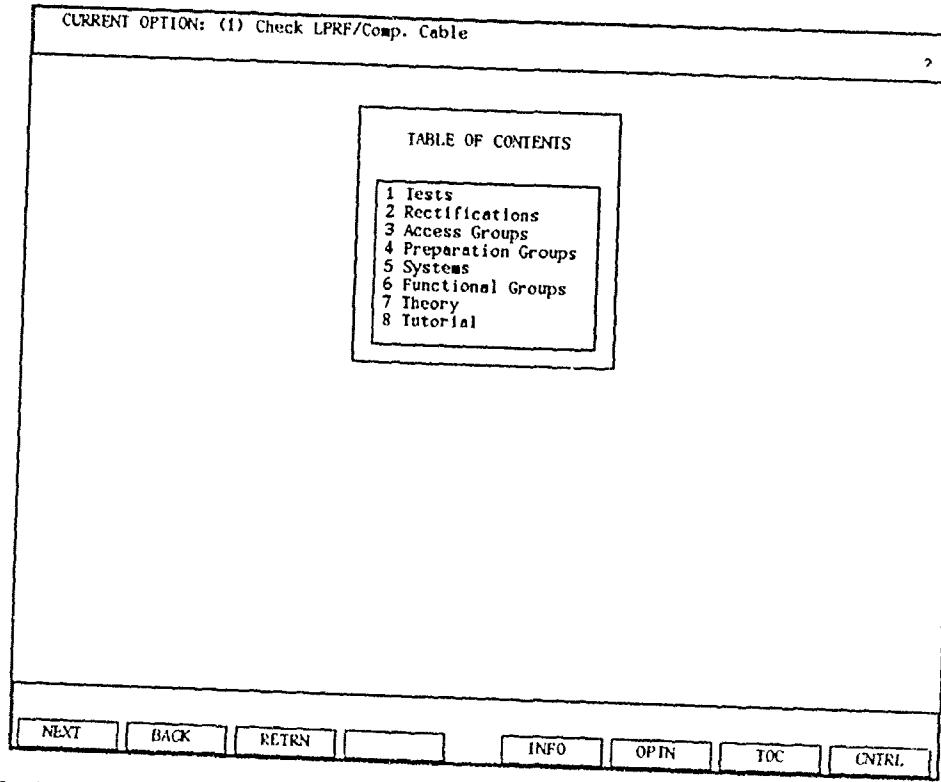
The shading on this diagram indicates that the LPRF, FCR Computer, and the LPRF Cables (Comp) are suspects in the failure and the LPRF Cables (Comp) will be tested by the CURRENT OPTION.



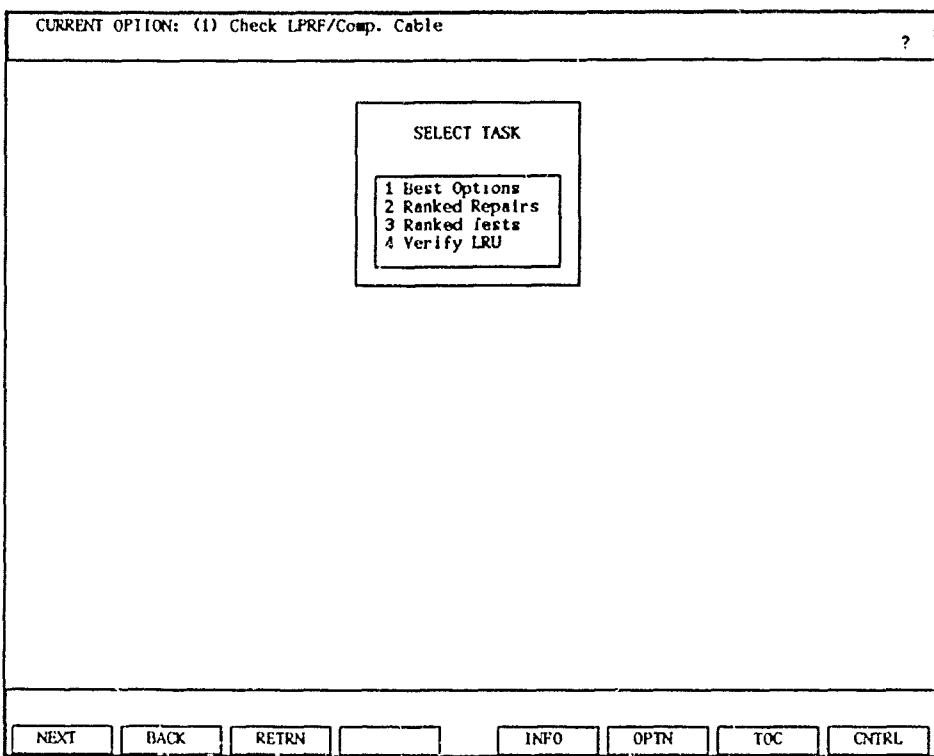
Screen 27 - If the technician wanted to see the block diagram for the FCR mode control, he or she would have selected #2 instead of #1 in screen 25. This screen is displayed for the FCR Mode Control.



Screen 28 - This is the block diagram for the FCR Power (option #3 in screen 25).



Screen 29 - If the technician wishes to view other procedures he or she would select the Table Of Contents menu option by pressing the "TOC" function key. The available information is divided into different categories, as shown in the menu. This allows the technician to select any and all available tests, rectifications, etc. and at any point to start their execution.

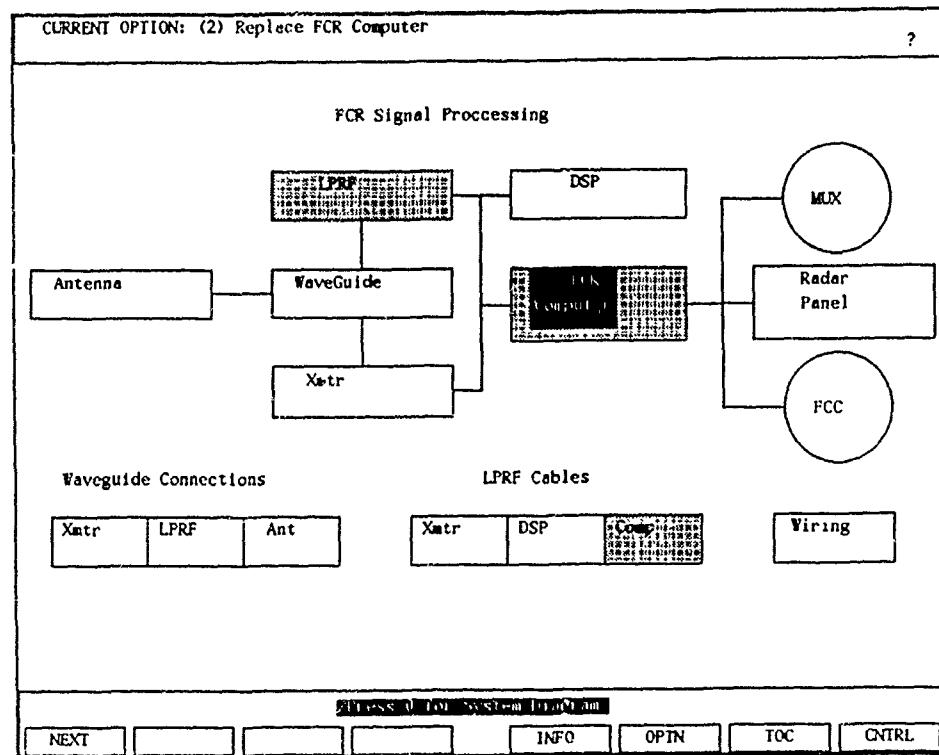


Screen 30 - At any point the technician can select the "OPTN" key to see what the recommended options are at this point. The "Best Options" list is the list of interleaved test/repairs recommended by the diagnostic module. "Ranked Repairs" displays the best-ranked repairs, and "Ranked Tests" displays the best-ranked tests. "Verify LRU" allows the technician to choose any LRU, and all repair and test options for that LRU will be presented in a menu.

CURRENT OPTION: (1) Check LPRF/Comp. Cable					?
BEST OPTIONS					
Description	Hours	Fail	Prob	Ref	Des
1. Check LPRF/Comp. Cable	0.4	20%	NA		
2. Replace FCR Computer	1.2	50%	9473A6		
3. Repair LPRF/Computer Cable	0.4	20%	N/A		
4. Replace Low Power RF Unit	1.9	30%	9473A4		

NEXT **BACK** **RETRN** **[]** **INFO** **OPTN** **TOC** **CNTRL**

Screen 31 - If the technician selected Best Options, this screen would be presented. It shows some of the factors that MDAS used in recommending the best action to perform. It also shows the rank order of the other possible recommended actions. Notice that even though "Replace FCR Computer" has a higher probability of causing this failure, 50% as opposed to 20% for the first choice, MDAS has recommended "Check LPRF/Comp. Cable" because of the lower time needed to perform the test. (See Section II for a full description on how MDAS makes its recommendations.)



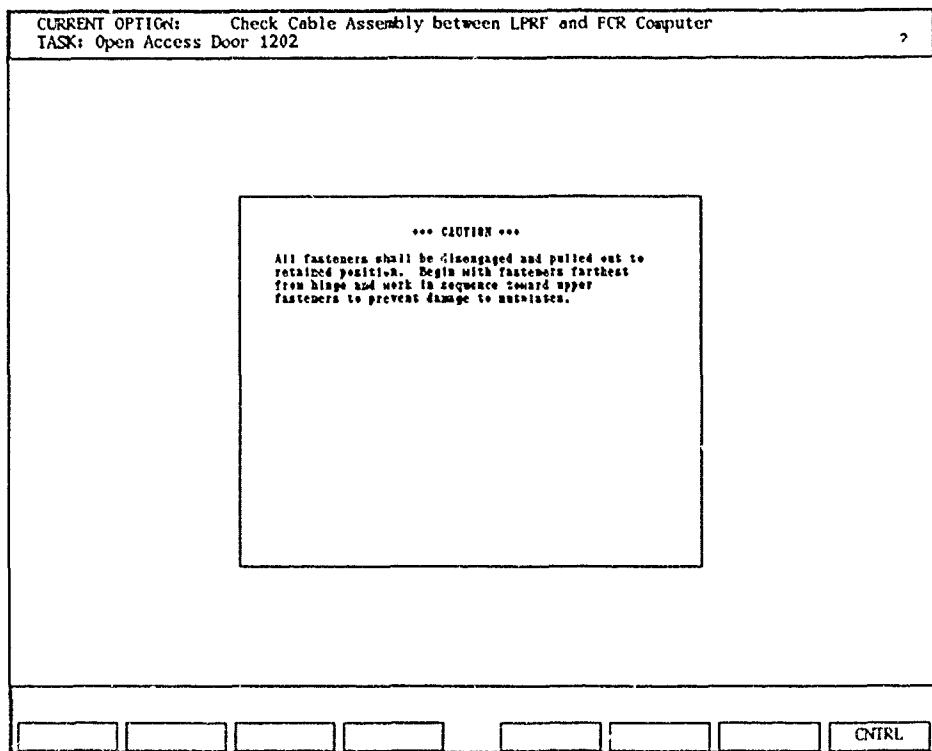
Screen 32 - This screen shows how the components are spanned for the second best option, "Replace FCR Computer" (upper left of the display). The technician may select this option for reasons of his or her own of which MDAS might have no knowledge.

CURRENT OPTION: Check Cable Assembly between LPRF and FCR Computer	>						
TASK: Check Cable Continuity							
INPUT CONDITIONS							
Applicability: All							
Required Conditions:							
• Aircraft Safe for Maintenance							
• Open Panel 1202							
• Power off							
Personnel Recommended: One							
Support Equipment: None							
Supplies (Consumables): None							
Other Recommendations: None							
NEXT	BACK	RETRN		INFO			CNTRL

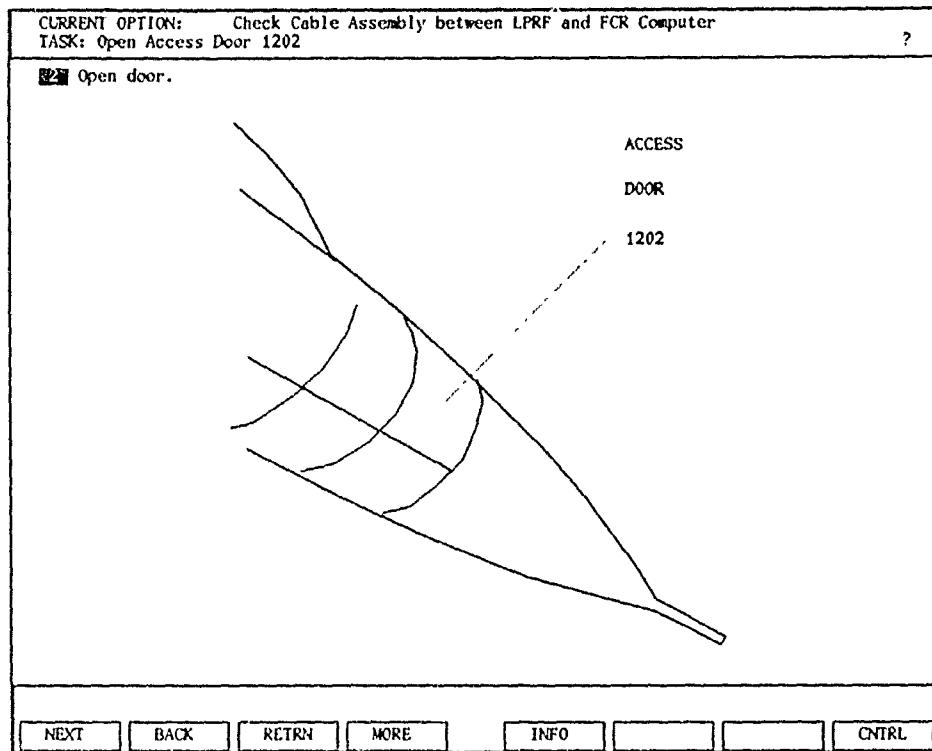
Screen 33 - The technician has chosen to start the diagnostic process with the first option after all (Check LPRF/Comp. Cable). The input conditions to this task (Check Cable Continuity) are shown as the first piece of information.

CURRENT OPTION: Check Cable Assembly between LPRF and FCR Computer	
TASK: Open Access Door 1202	
INPUT CONDITIONS	
<p>Applicability: All</p> <p>Required Conditions:</p> <ul style="list-style-type: none">• Aircraft safe for maintenance. <p>Personnel Recommended: One</p> <ul style="list-style-type: none">• Technician opens and closes door. <p>Support Equipment: Maintenance Platform, Type B-4A or equivalent.</p> <p>Supplies (Consumables): None</p> <p>Other Recommendations: None</p>	
<p style="text-align: center;">NEXT BACK RETRN INFO CNTRL</p>	

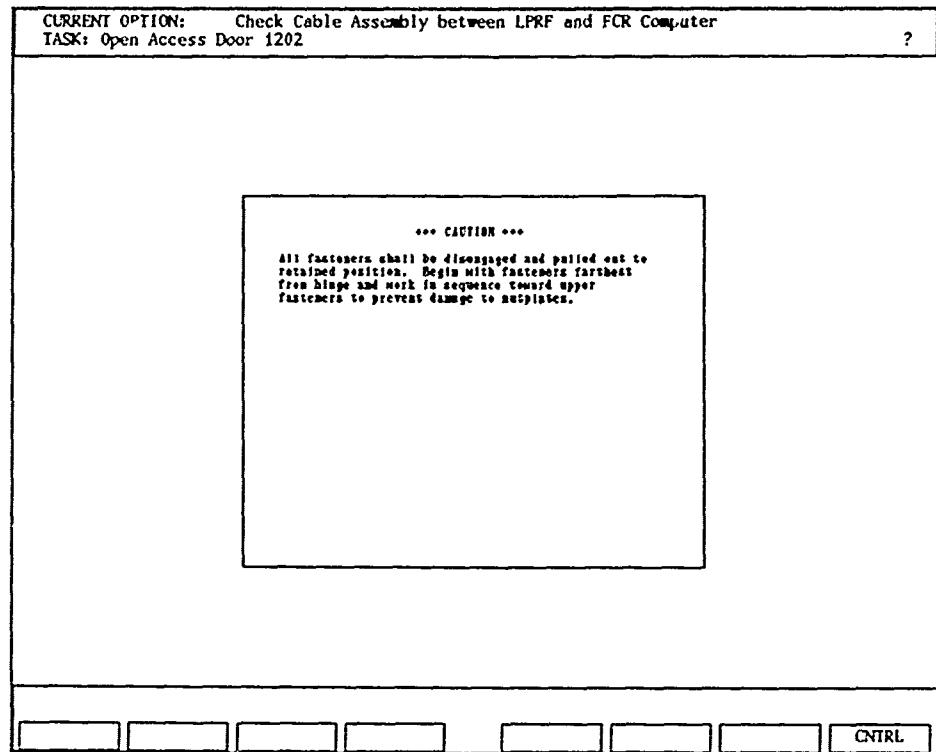
Screen 34 - The procedure to open access door 1202 is automatically linked to this task and the input conditions are displayed for the technician. It indicates that a Maintenance Platform will be required and only one person is needed to do the procedure. The technician will press the NEXT function key after reading the text.



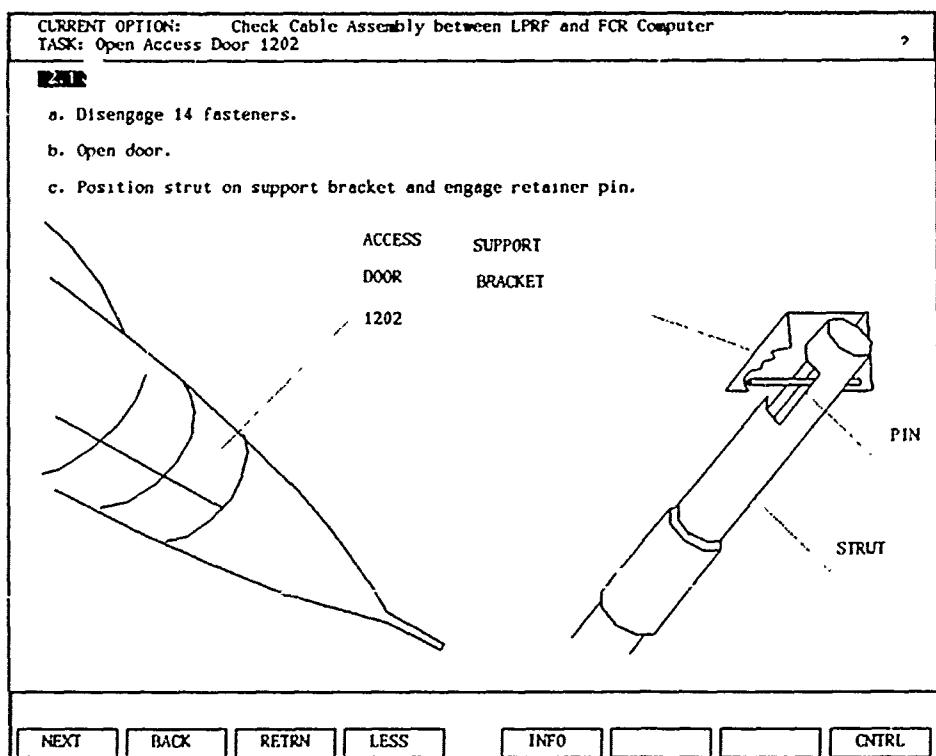
Screen 35 - The procedure for opening the access door also has a Cautio.n. To proceed past this point, the technician must press the "Enter" key on PCMAS rather than the "NEXT" function key. This will prevent the technician from simply pressing the next key without acknowledging the cautions.



Screen 36 - A graphic to locate the proper door is displayed to the technician. This is the expert track of data for the task. If more detail is desired, the technician can press the "MORE" function key.



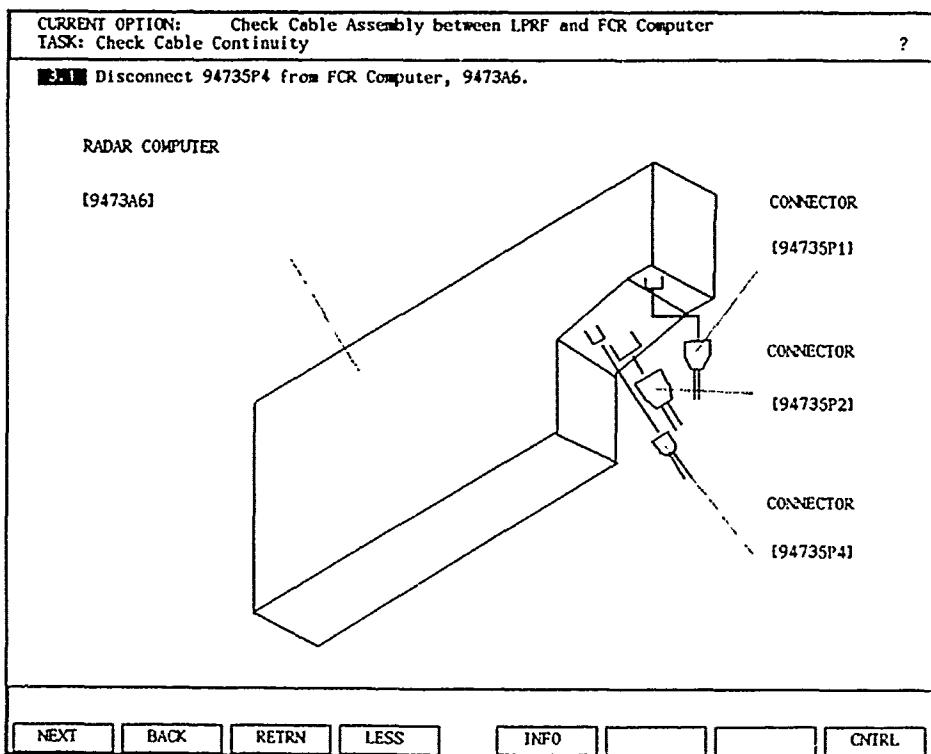
Screen 37 - The novice track of data also contains a caution that must be read and responded to with the "Enter" key.



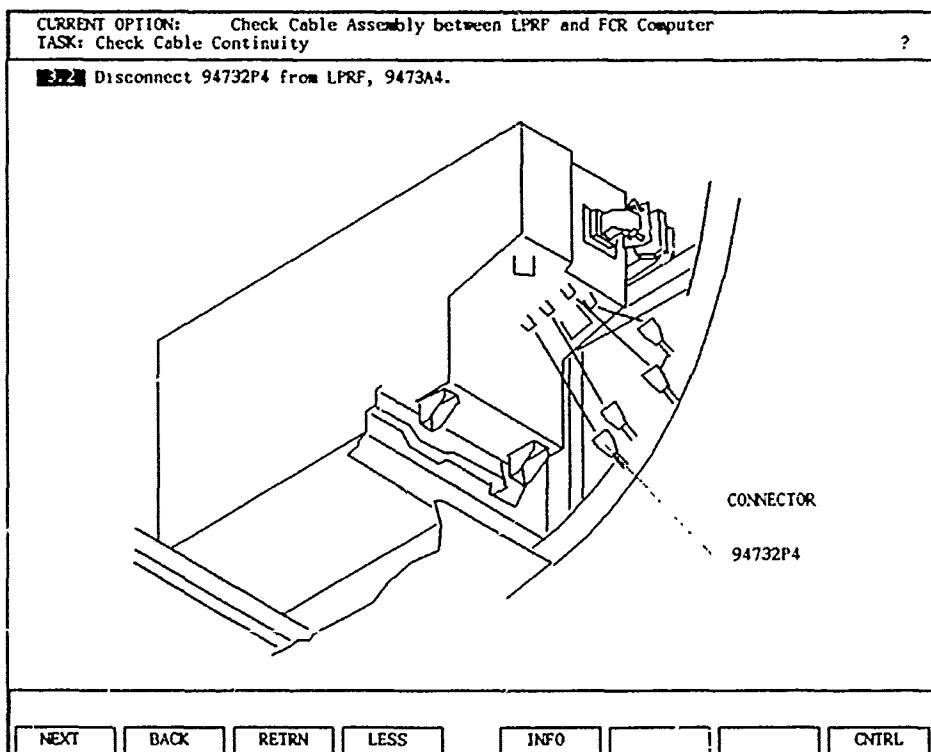
Screen 38 - The novice track displays more detail about the use of the door strut and support bracket.

CURRENT OPTION: Check Cable Assembly between LPRF and FCR Computer							
TASK: Check Cable Continuity							
?							
<input checked="" type="checkbox"/>							
<table border="1"><tr><td>1 Yes</td></tr><tr><td>2 No</td></tr></table>		1 Yes	2 No				
1 Yes							
2 No							
Does continuity exist between 94735P4 (at FCR Computer) and 94732P4 (at LPRF) at the pins below?							
Check Continuity: AWI							
FROM	TO						
1 94735P4 Center Pin	94732P4 Center Pin						
2 94735P4 Shield	94732P4 Shield						
BACK	RETRN	MORE	INFO				CNTRL

Screen 39 - In the expert track, this is the first screen the technician will see for the actual continuity check procedure. The to/from pins are presented in a table for best access. This screen also displays a question (Yes/No) that must be answered to proceed. MDAS will rely on the Yes or No response to this question to recommend the next best action.



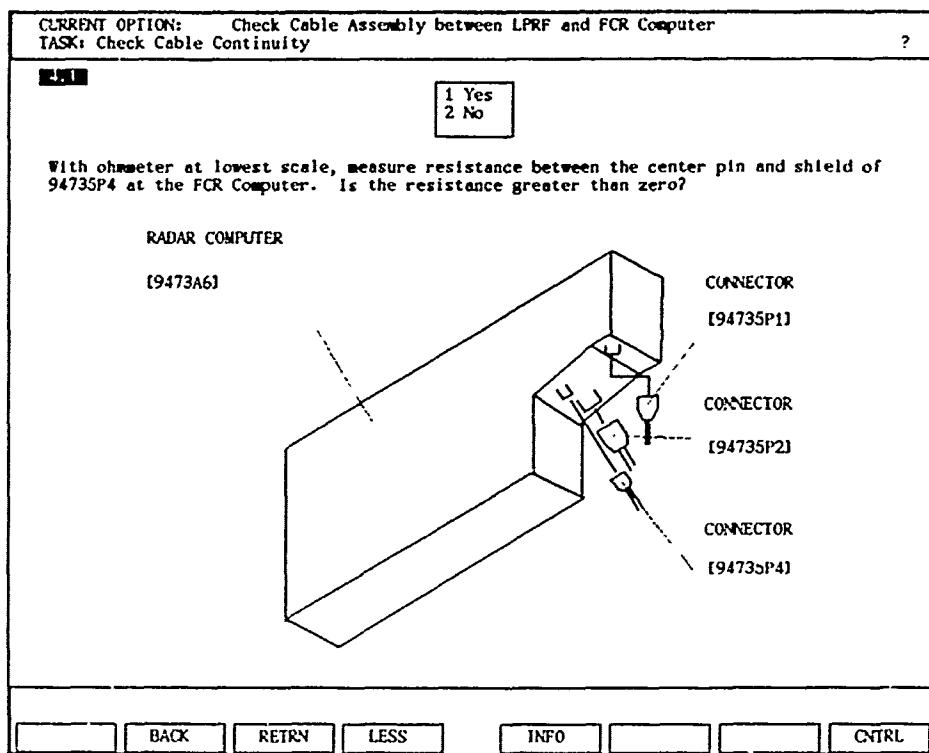
Screen 40 - The novice track of the same task shows a graphic to identify the cables attached to the FCR Computer.



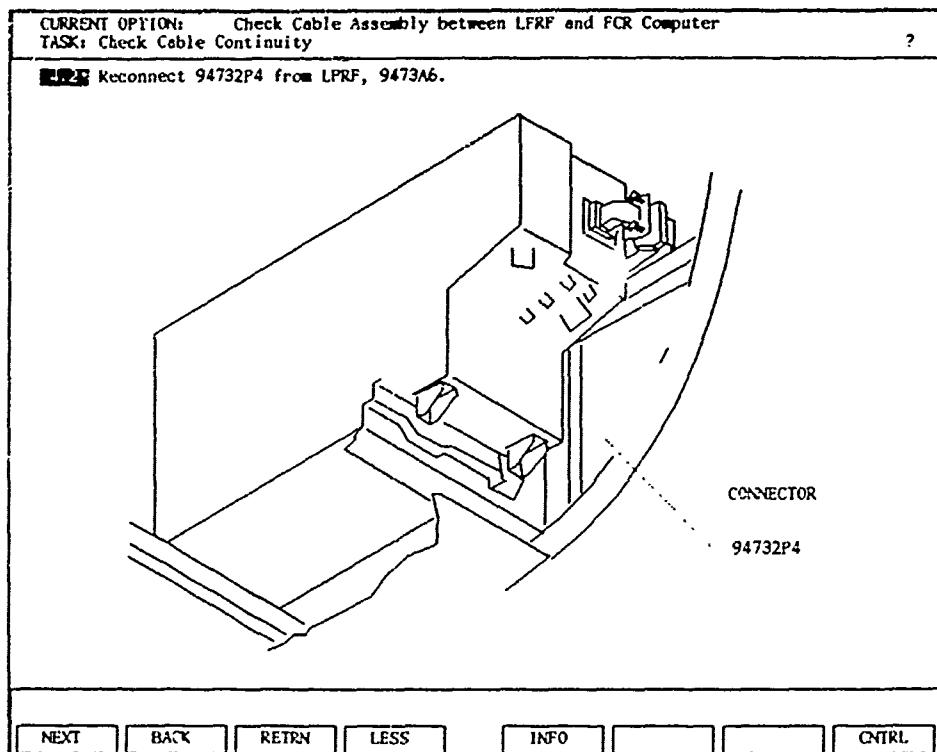
Screen 41 - The novice track then shows a graphic to locate the other end of the cable at the LPRF.

CURRENT OPTION: Check Cable Assembly between LPRF and FCR Computer		?						
<input type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/>								
<input type="checkbox"/> 1 Yes <input type="checkbox"/> 2 No								
With ohmmeter at lowest scale, verify zero ohms between the following pins. Do both sets of pins show zero ohms?								
Check Continuity: AW1								
FROM	TO							
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">1</td> <td>94735P4 Center Pin</td> <td>94732P4 Center Pin</td> </tr> <tr> <td>2</td> <td>94735P4 Shield</td> <td>94732P4 Shield</td> </tr> </table>			1	94735P4 Center Pin	94732P4 Center Pin	2	94735P4 Shield	94732P4 Shield
1	94735P4 Center Pin	94732P4 Center Pin						
2	94735P4 Shield	94732P4 Shield						
<input type="button"/> <input type="button"/> BACK <input type="button"/> RETRN <input type="button"/> LESS <input type="button"/> INFO <input type="button"/> <input type="button"/> <input type="button"/> CNTRL								

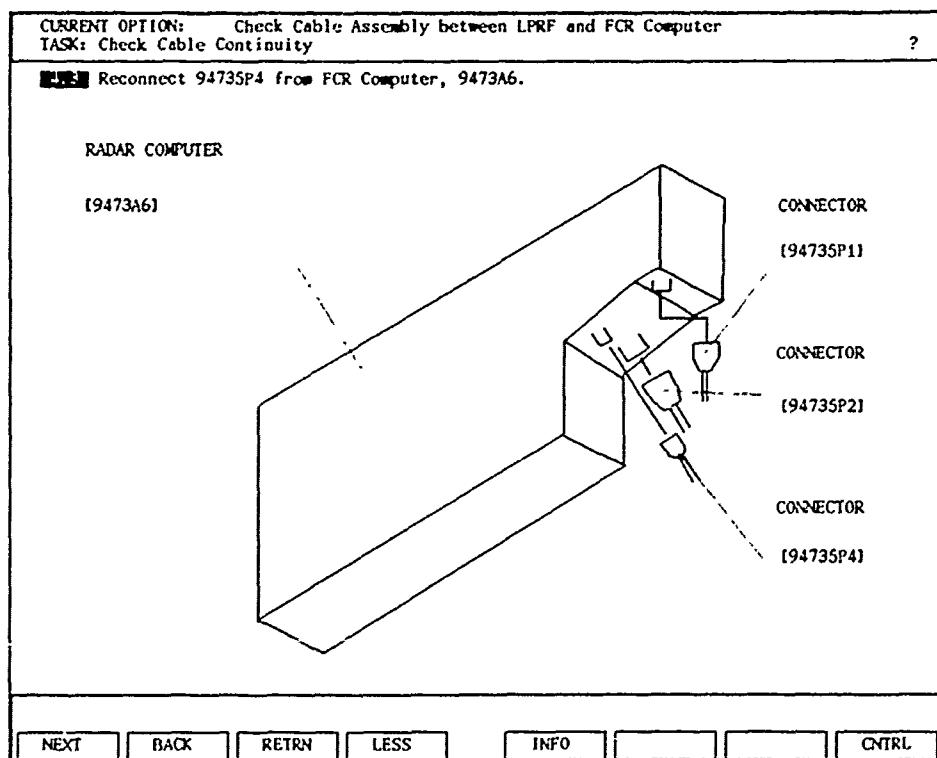
Screen 42 - The novice track asks the same question that was asked of the expert in screen 38, except this question helps the technician set up the ohmmeter and interpolate the readings. For this scenario, the technician indicated that he had found a bad cable by entering "NO."



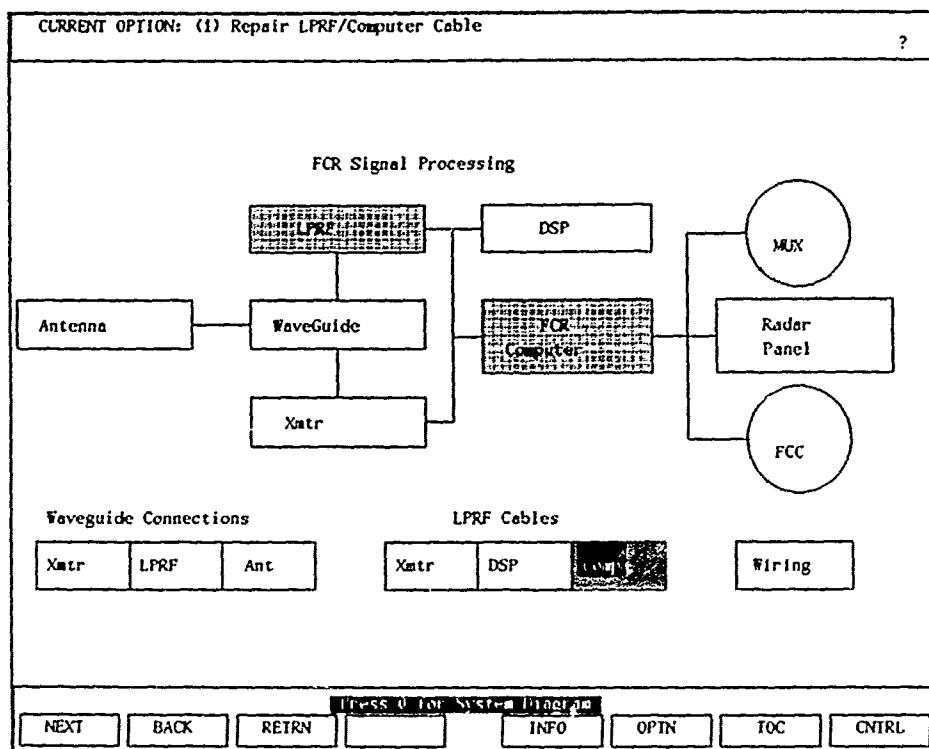
Screen 43 - This novice step makes sure that the pins are not shorted to ground and presents a graphic to help locate the cables. The technician indicates that the cable is not shorted to ground in this scenario by again answering "NO."



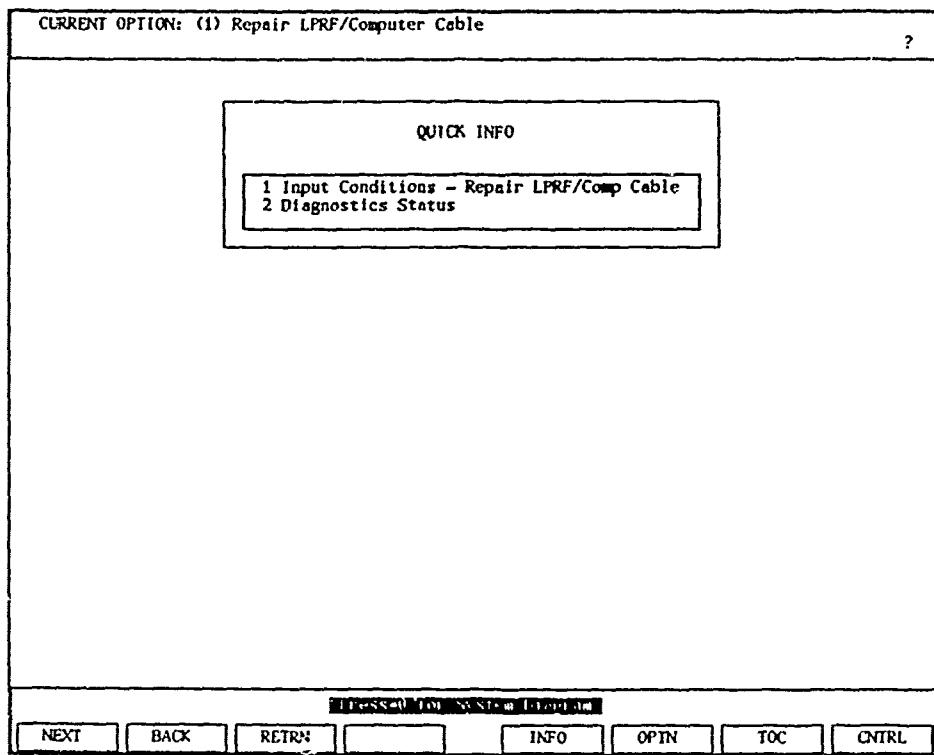
Screen 44 - This novice screen shows the first reassemble step and a supporting graphic.



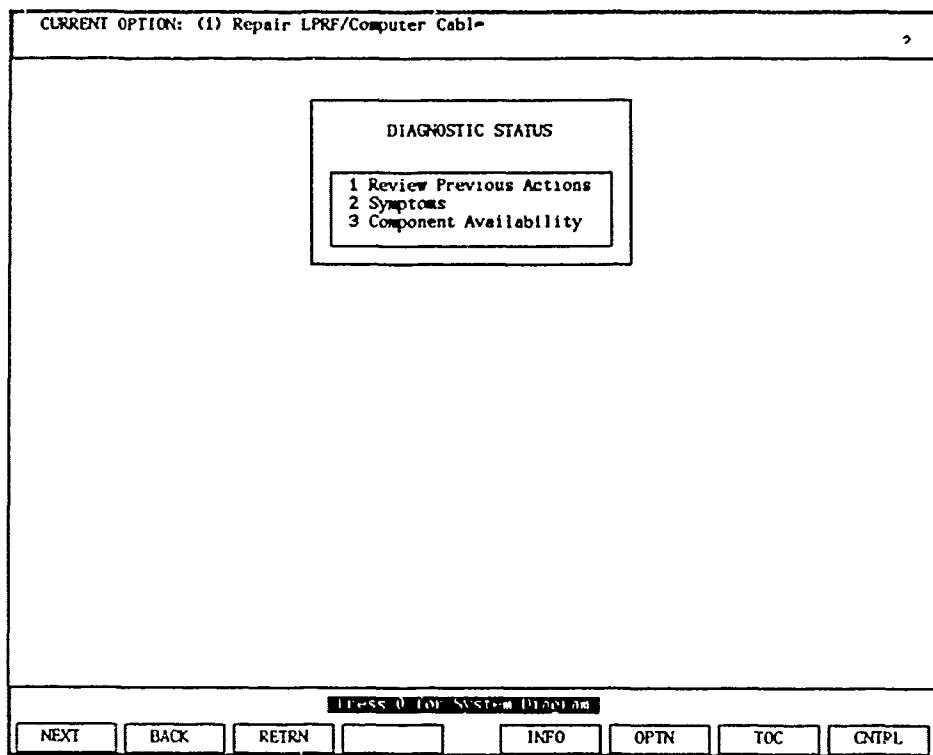
Screen 45 - This novice screen shows how to complete the reassemble procedure.



Screen 46 - When the reassembly task is complete, the system graphic is re-displayed. The shading has been changed to indicate that the LPRF and FCR Computer have been downgraded as possible causes of the failure (they are a lighter shade of grey), and are members of the "Maybe" set for diagnostic purposes. This figure also shows that the current option is "Repair LPRF/Computer Cable," which was found to have failed in the last step.



Screen 47 - If the technician presses the "INFO" function key when Screen 45 is being displayed, the Quick Info menu will appear. At this point, the technician can choose to view the input conditions or review the diagnostic status.



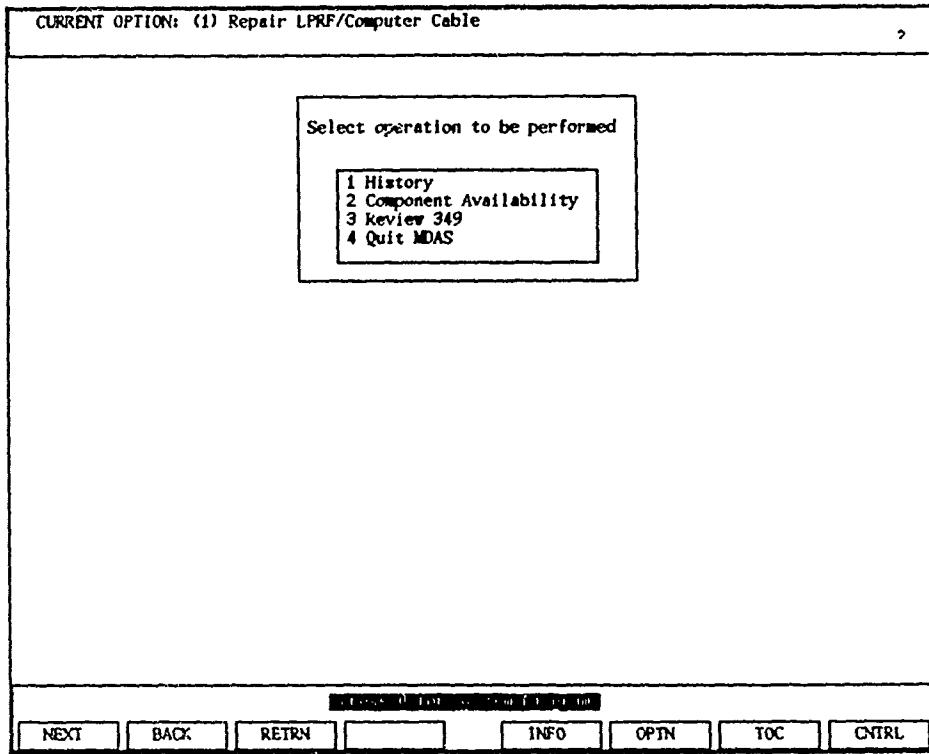
Screen 48 - When option 2, "Diagnostic Status", is selected at the previous screen, this menu appears. At this point, the technician is given the choice of reviewing his or her previous actions, the symptoms, or the availability of replacement parts.

CURRENT OPTION: (1) Repair LPRF/Computer Cable		
REVIEW PREVIOUS ACTIONS		
Action Taken	Status	Hours
Check LPRF/Comp. Cable	FAIL	0.1
Open Access Door 1202	X	0.1

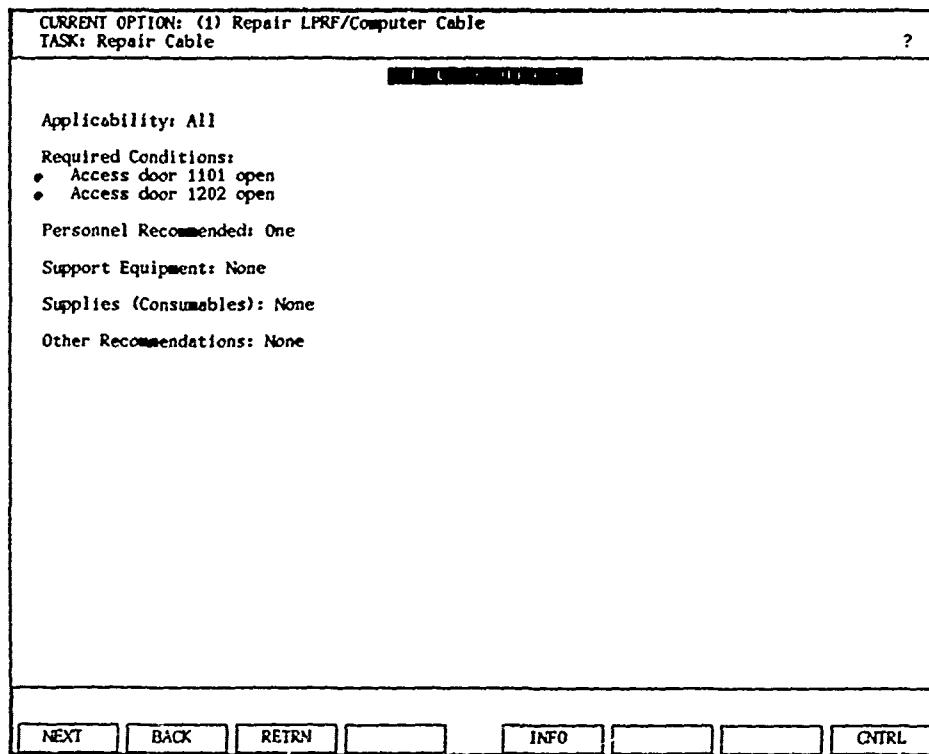
PRESS 0 For System Diagram

NEXT	BACK	RETRN		INFO	OPTN	TOC	CNTRL
------	------	-------	--	------	------	-----	-------

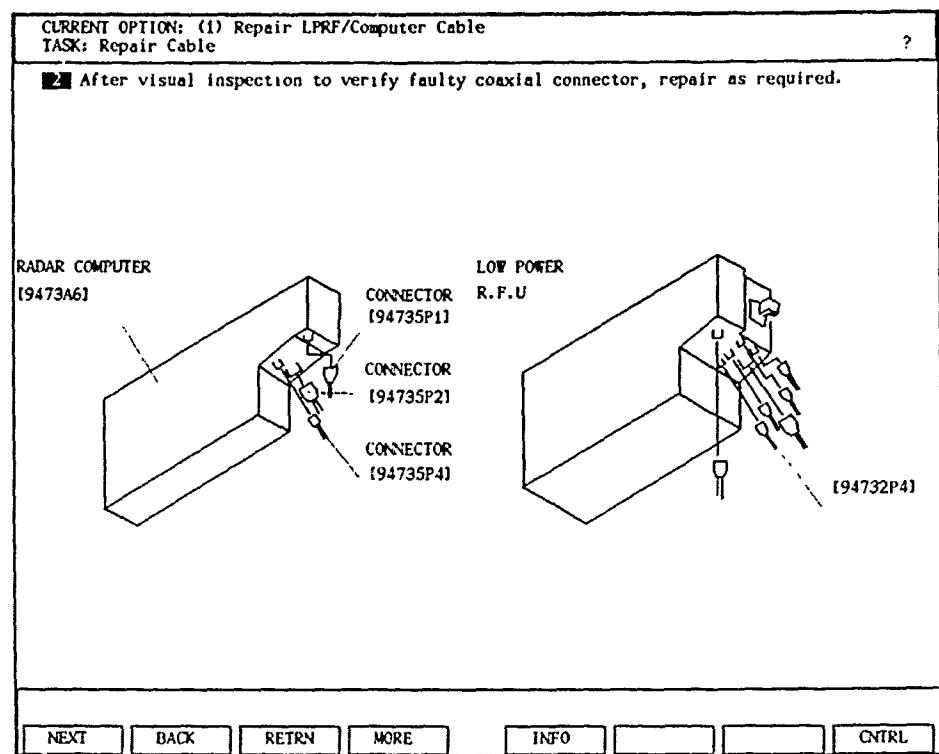
Screen 49 - This screen shows the previous actions taken thus far in the repair procedure. It shows that the test of the LPRF/Comp. Cable has failed (the cable is bad) and that an access door is still open.



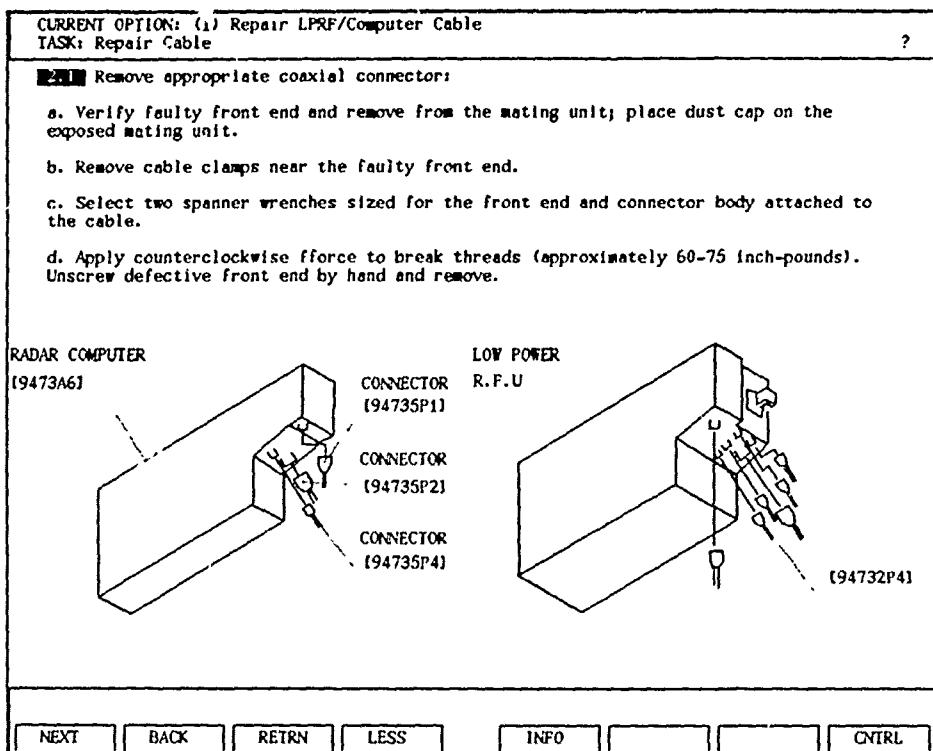
Screen 50 - The technician has the ability to terminate the diagnostic run at any point through the menu displayed when the "CNTRL" function key is pressed. Other options available here are: (a) review the history of the aircraft, (b) see which LRUs are available from supply (simulated for this demonstration), or (c) review the 349 form that started the maintenance action. If "Quit MDAS" is selected, another menu is presented with two options: (1) end the maintenance session completely, or (2) suspend the session for resumption later at the same point in the diagnostic process.



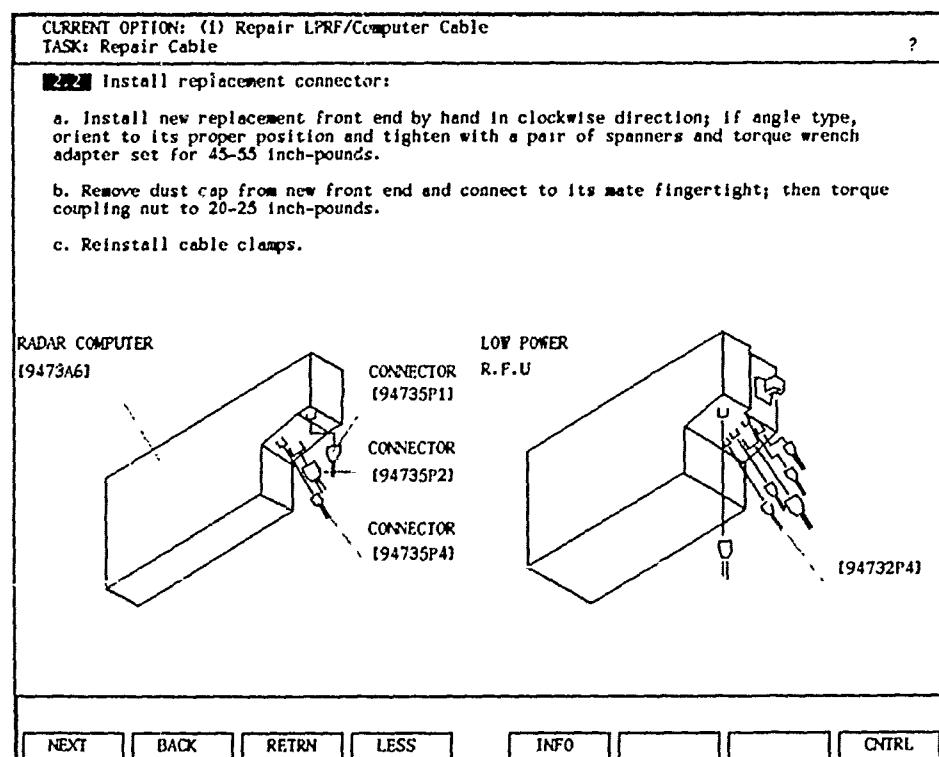
Screen 51 - If the technician were to press "NEXT" rather than any of the menu items on the last screen, the procedures for the "CURRENT OPTION" would be invoked. In this case, the Input Conditions for the procedure are displayed for review.



Screen 52 - This screen shows the expert track for the task of repairing the cable. Notice that the "More" function key is available to allow switching to the novice track if needed.



Screen 53 - The "More" function key has been pressed and the details of the cable repair in the novice track are presented to the technician. Notice that the "More" function key has been replaced by a "Less" key. This allows for switching back to the expert track.

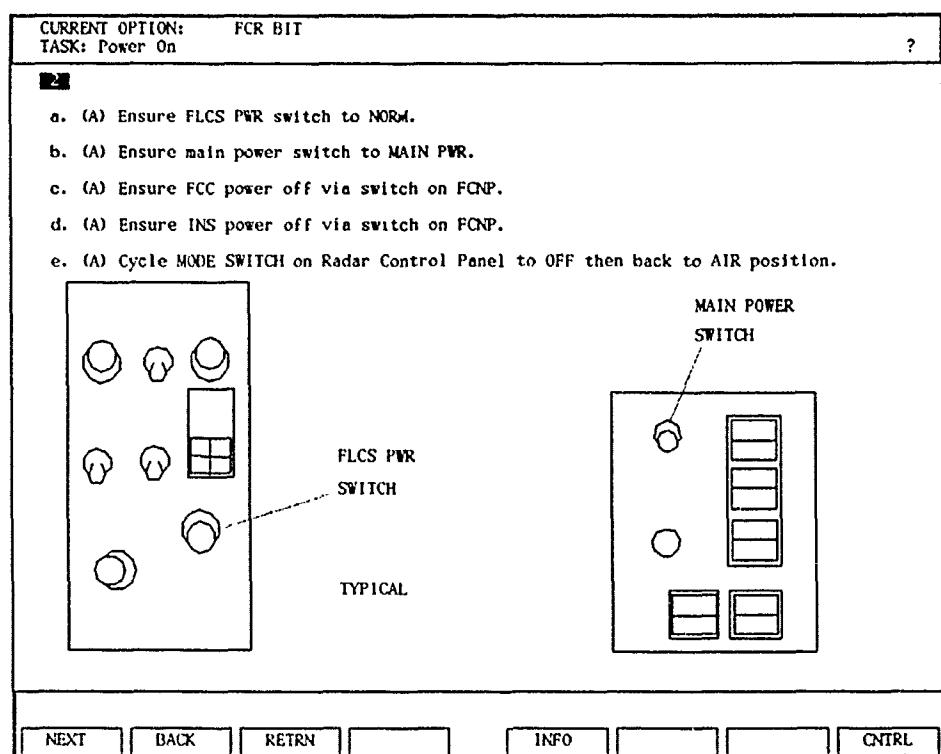


Screen 54 - This is the second screen of instructions at the novice track for the cable repair.

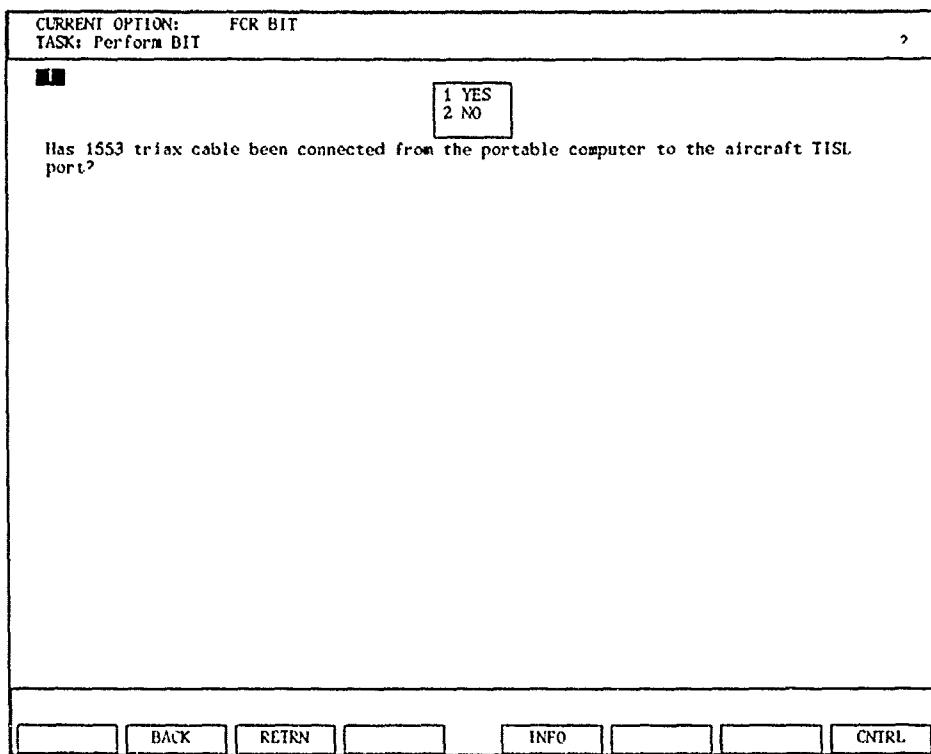
CURRENT OPTION: FCR BIT	TASK: Power On	?					
INPUT CONDITIONS							
Applicability: All							
Required Conditions:							
• Aircraft safe for maintenance							
• Power on aircraft							
• INS off							
• FCC off							
Personnel Recommended: One							
Support Equipment: None							
Supplies (Consumables): None							
Other Recommendations: None							
NEXT	BACK	RETRN		INFO			CNTRL

Screen 55 - Once the repair is complete and the technician presses the "NEXT" function key from either the novice or the expert track, the input conditions for the next task are displayed. In this case, the task is the execution of the Built-In Test to verify that the cable repair was successful.

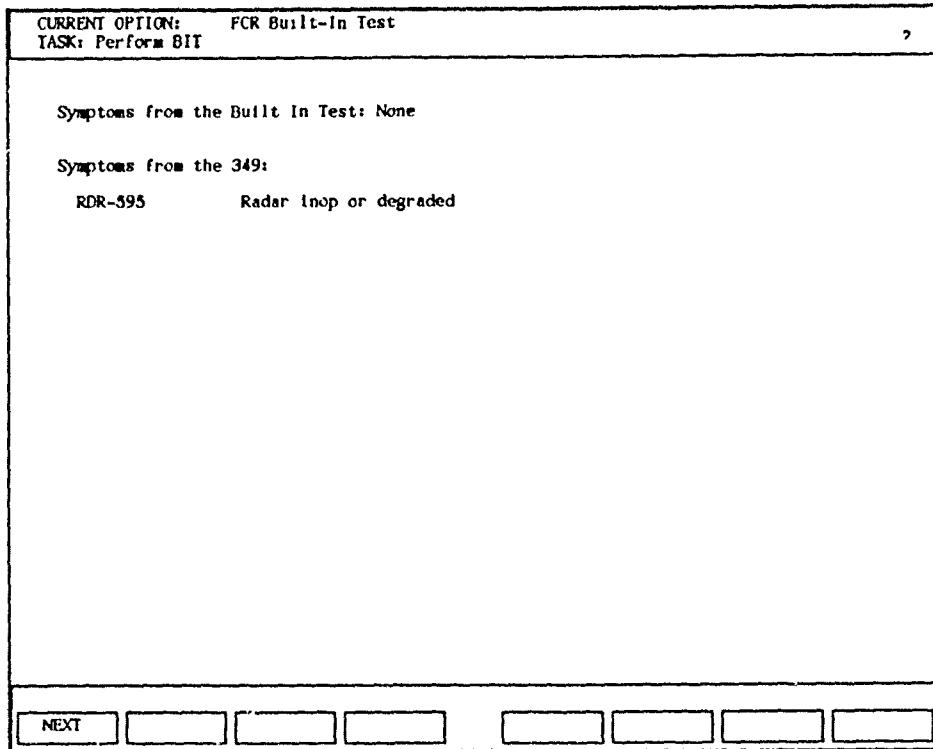
Before this can occur, the aircraft must have been safed, power applied, and the INS and FCC shut off. Shutting the INS and FCC off is necessary to allow PCMAS to gain control of the bus.



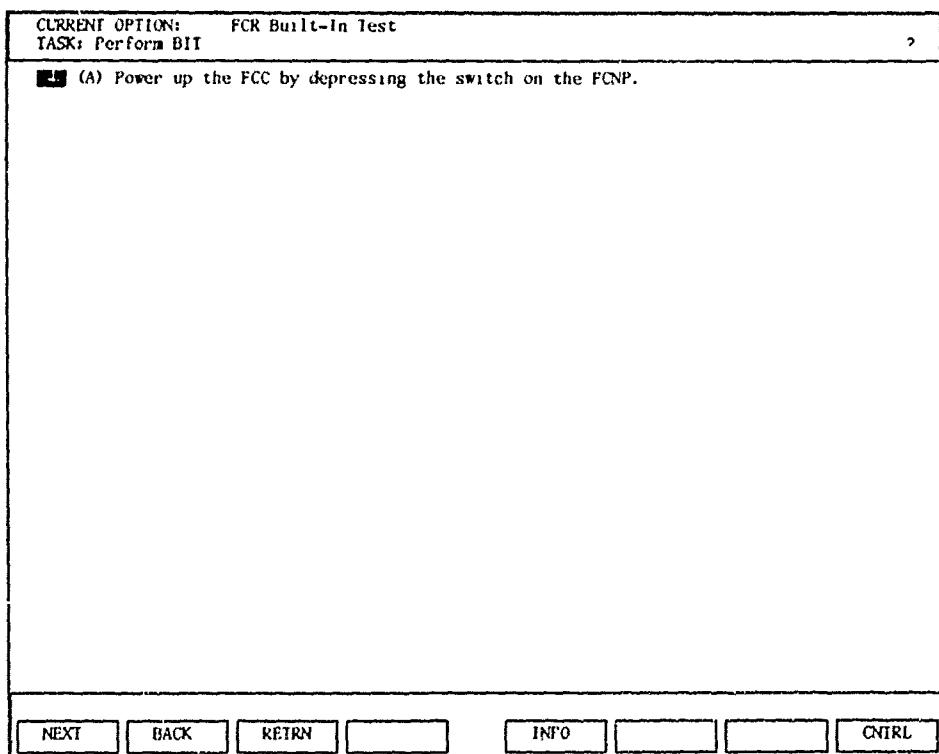
Screen 56 - The complete setup to perform BIT is shown in this screen. Each switch is identified and located in the cockpit for the maintenance technician.



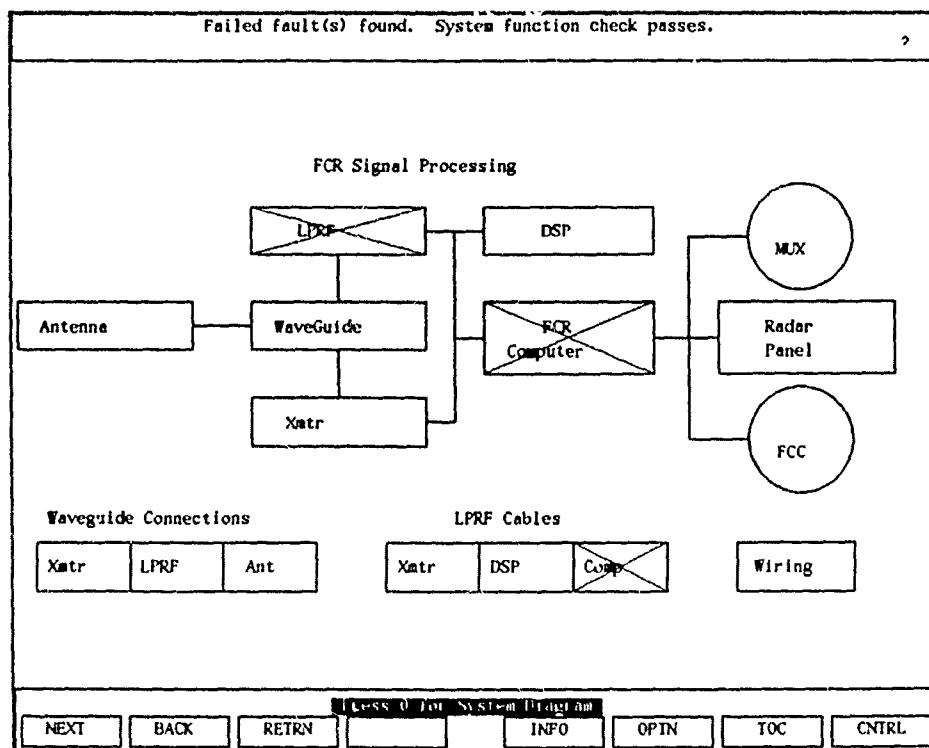
Screen 57 - This question is asked of the maintenance technician as the last step in preparation for BIT execution. If the technician answers that the portable is connected to the aircraft via the TISL port, the portable will initiate BIT.



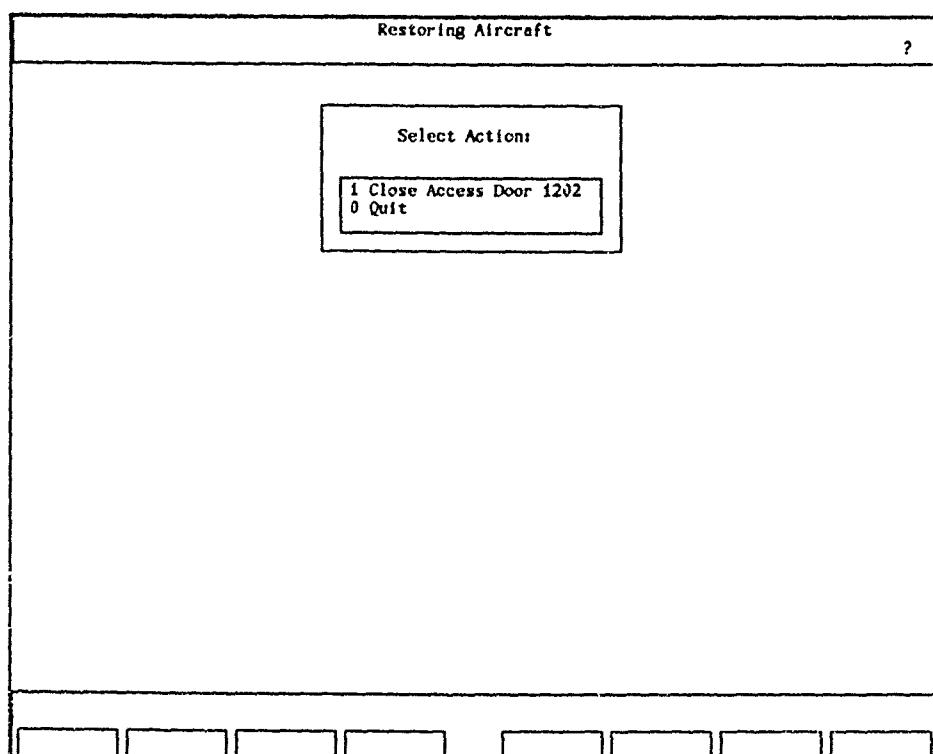
Screen 58 - This screen shows the results of the BIT execution (no faults found) and the original MFL symptom for reference.



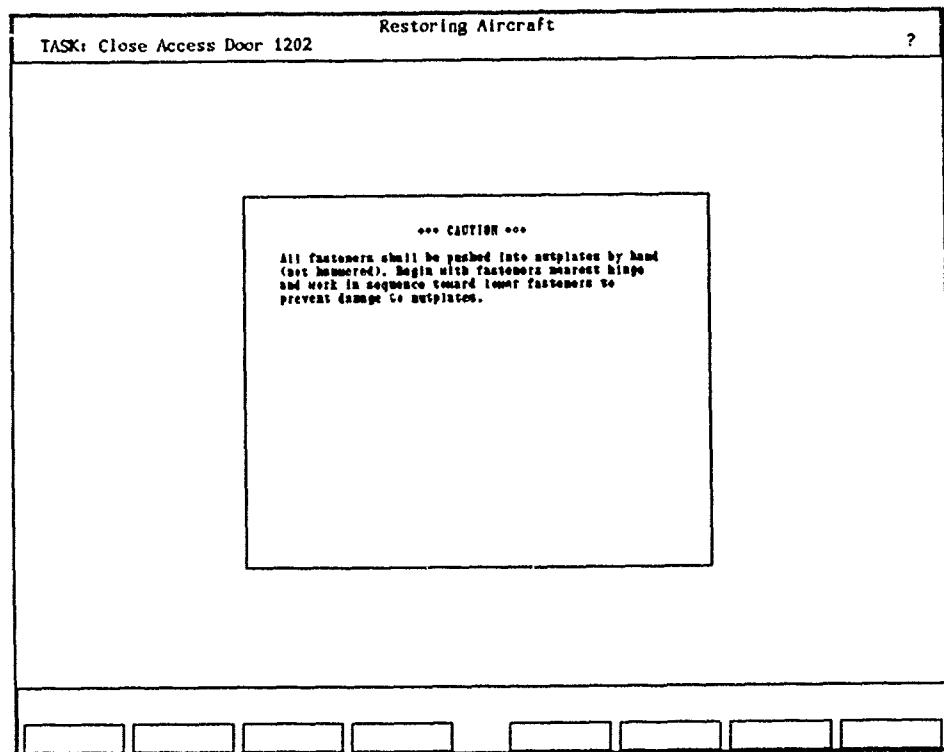
Screen 59 - After running the BIT procedure, the technician is directed to return the cockpit to its operational condition.



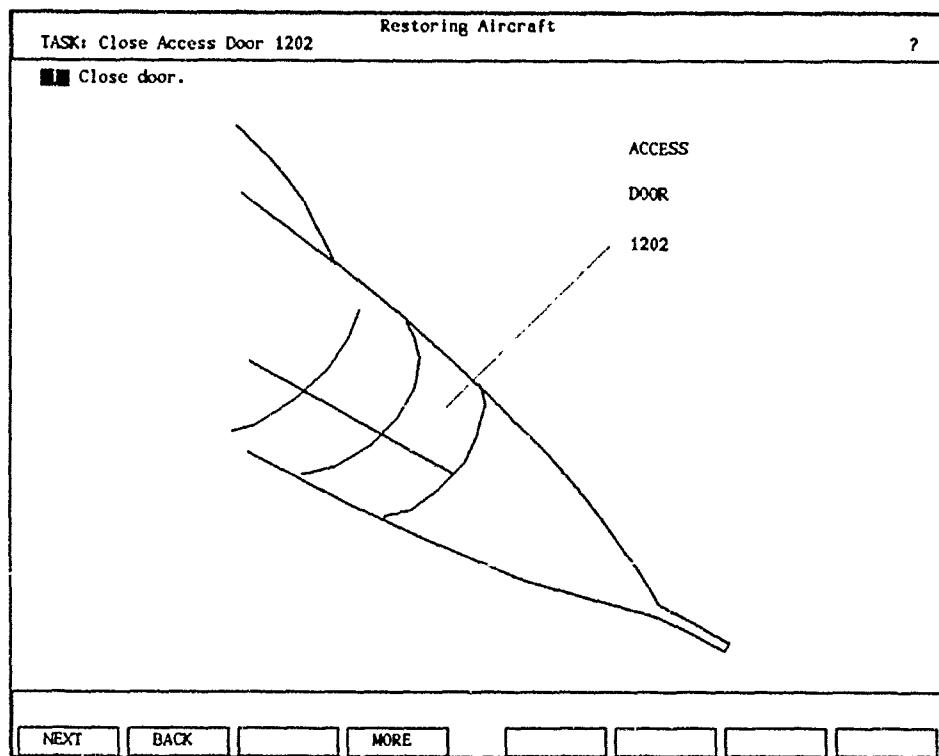
Screen 60 - The system block diagram is again presented, showing that all symptoms have been excused and the functional check has passed.



Screen 61 - Now that the diagnostic process is complete, the technician can either close up the aircraft or quit entirely.



Screen 62 - The option to "Close Access Door 1202" was selected so the system presents this procedure to the technician. This Caution is automatically linked to the procedure to ensure the proper order of fastener reconnection.



Screen 63 - The expert track for the procedure.

MAINTENANCE DATA COLLECTION KEYCODE					
Man Number	:	33333	System	:	9461
JCN	:	1284212	Priority	:	2
Work Center	:	A7CS	Start Hour	:	0003
A/C ID Number	:	810794	Stop Day	:	179
Location	:	Bay12	Stop Hour	:	0900
Time Spc Req	:	1245	Crew Size	:	2
Crit ID	:	N/A	Type Maint	:	B
Crit Name	:	N/A	When Disc	:	D
DISCREPENCY	:	Rader inop or degraded			
<input type="button" value="Press enter to continue."/>					

Screen 64 - After the close-up procedure is complete, the 349 form is again displayed. At this point, the portable has entered the Stop Day and Stop Hour fields.

WORK UNIT CODE	ACTION TAKEN	HOW MAL	UNITS	TIME START STOP	STATUS
74A99	G	943	01	1622 1624	CW
CORR ACTION					
Repair LPRF/Computer Cable					
PRESS PAPER TO CONTINUE.					

Screen 65 - The bottom part of the 349 is shown in this screen with the data supplied automatically. The WUC has been completed along with the "action taken" code and the HOW MAL. An English language description of the fault is also provided. These data will form a part of the history file for the next maintenance action on this tail number.

REVIEW PREVIOUS ACTIONS		
Action Taken	Status	Hours
Check LPRF/Comp. Cable	FAIL	0.1
Open Access Door 1202	CW	0.1
Repair LPRF/Computer Cable	CW	0.1
FCR Built-In Test	PASS	0.1

Press any key to continue.

Screen 66 - A complete list of all actions taken, their status, and the time to complete are shown in this screen.

TURN OFF POMAS UNIT END OF SESSION

Screen 67 - End of Session.